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Cotton Production and Water Quality

Economic and Environmental Effects of Pollution Prevention

Stephen R. Crutchfield, Marc O. Ribaudo,
LeRoy T. Hansen, and Ricardo Quiroga

Water Quality

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Abstract

Cotton production, compared with other crops, is less likely to cause erosion-induced water-quality problems because cotton acreage is not the major source of erosion in most regions. For cotton production, the most widespread potential damages to water quality are from nitrates in fertilizer polluting ground water and pesticides contaminating surface water. This damage could be reduced by restricting chemical and fertilizer use on all cotton production, but doing so could reduce cotton yields and raise cotton prices. The same level of water-quality improvement could be achieved at less cost by targeting the chemical use or erosion restrictions only to cotton farms with the most vulnerable soils. Data come from a 1989 USDA survey of cotton producers.

Keywords: Cotton, water quality, ground water, surface water, pesticides, soil erosion, farm income

Acknowledgments

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Summary

Environmental damage to surface and ground water posed by cotton farming may be reduced, with only limited effects on yields and prices, if restrictions on agrichemical use or production are applied to just those acres most vulnerable to water-quality problems. The most widespread potential damages are from nitrates in fertilizer that can pollute ground water and pesticides that can contaminate surface water.

Production of cotton appears less likely than other crops to cause erosion-induced water-quality problems because cotton acreage is not the major source of cropland erosion in most regions. Widespread restrictions on the use of chemicals likely to leach, dissolve in cropland runoff, or attach to eroding soils may reduce the risk of water-quality degradation, but may also raise cotton prices by reducing yields.

These conclusions flow from USDA's 1989 Cotton Water Quality Survey that gathered data on cotton agricultural chemical use and related production practices and resource conditions in 14 cotton States. Data gathered on the use of fertilizers, herbicides, insecticides, and other agricultural chemicals were analyzed to assess the potential water-quality problems that may be associated with cotton production.

The study's results highlight the importance of targeting pollution-prevention programs to attain the most cost-effective environmental protection strategies. Restricting the use of environmentally damaging chemicals on all cotton acreage could reduce the overall potential for water-quality impairment, but could raise cotton prices by as much as 31 percent. More specific chemical use restrictions, targeted to acreage considered at greatest water-quality risk, could achieve nearly the same level of environmental protection, but would limit price increases and reduce yield losses. Modifying production practices to reduce soil erosion could generate $25 million in economic benefits by reducing sedimentation in surface water systems.

The 1989 survey covered 10.5 million acres, 99 percent of all cotton acreage. USDA researchers applied several screening procedures to the data to assess the potential for cotton agricultural chemical use to affect water quality. Estimates of cropland erosion on cotton acreage were used to estimate delivery of suspended sediment to surface water systems. Other screening procedures used information on soil properties and the chemical properties of applied agrichemicals to characterize cotton cropland by the relative potential for pesticides to leach to ground water or move to adjacent surface water bodies.

Researchers used an econometric model of cotton production to estimate the relationship between nitrogen fertilizer application, conservation practices, water and other input use, and yields. This model was used to evaluate the effect on cotton production of requiring farmers to use conservation practices on erosive acreage and of limiting nitrogen use on acreage thought to be vulnerable to nitrate leaching.

Expert opinion on the effect of agrichemical restrictions on cotton yield was used to evaluate policies to prevent pollution by banning certain agrichemicals felt to pose the greatest risk to water quality. Simulation procedures estimated the possible effects of restricting use on only acreage ranked by the screening procedures as highly vulnerable to chemical loss. Yield losses derived from these procedures were used as input to a large-scale model of the agricultural economy to estimate the effects of these policies on farm prices, income, and consumer welfare.

Cotton is only one of many crops whose production can affect environmental quality. Reducing erosion or chemical use on cotton farms alone may not improve water quality significantly if other crops within a given area also pollute local waters. ERS research will also assess the environmental and economic effects of pollution-prevention strategies on a more comprehensive scale.

Cotton Production and Water Quality

Economic and Environmental Effects of Pollution Prevention

Stephen R. Crutchfield
Marc O. Ribaudo
LeRoy T. Hansen
Ricardo Quiroga

Introduction

Production of food and fiber, including cotton, may have unintended effects on ground and surface water resources. Concern about the potential for agricultural production to impair water quality has resulted in new legislation and policy initiatives that seek to minimize these effects. This concern arises, in part, out of the possibility that exposure to dissolved agricultural chemicals in water may pose a health risk. The President's 1989 Water Quality Initiative is designed to protect the public from unnecessary exposure to chemicals in water by fostering agricultural production practices that reduce the likelihood that byproducts of crop production may enter surface or ground water.

As part of the President's Water Quality Initiative, the Economic Research Service (ERS) and the National Agricultural Statistics Service (NASS) of the U.S. Department of Agriculture (USDA) surveyed cotton producers in 14 Southern and Western States in 1989. Information from the survey provides a comprehensive accounting of field applications of pesticides and fertilizers on the 1989 cotton crop. The survey accounted for cotton production practices on 10.5 million acres (99 percent of the total U.S. planted cotton acreage of 10.6 million acres).

This report uses data from the survey and simple screening models to characterize the scope and extent of potential effects of cotton production on water pollution, both of ground water and surface water. It assesses several strategies for reducing water pollution, both for their environmental effectiveness and for their economic effects on cotton farmers through yield losses and price increases.

The study's results highlight the importance of targeting pollution-prevention programs to attain the most cost-effective environmental protection strategies. Restricting chemical use for only cotton farmers who plant acreage most susceptible to water-quality problems achieves nearly the same reduction in pollution vulnerability as restricting usage for all cotton farmers. Restricting only acreage with the greatest risk of pollution also reduces the adverse economic effects on cotton farmers and consumers; yield losses are reduced by up to 1 million bales and smaller increases in cotton prices result.

Cotton, however, is only one of many agricultural products whose production may affect environmental quality. Reducing erosion or chemical use on cotton farms alone may not improve water quality significantly if production of other crops within the area is also polluting local water resources. Cotton has been a major U.S. cash crop for nearly 200 years. In 1989, cotton was the fifth most valuable field crop ($3.9 billion) after corn ($17.9 billion), hay ($11.5 billion), soybeans ($10.9 billion), and wheat ($7.5 billion). Approximately 9.5 million acres of cotton were harvested in 1989, or about 3.7 percent of harvested U.S. cropland devoted to major field crops. Production in 1989 in the 14 States covered by the survey was an estimated 12.2 million bales. The 14 States are divided into the following regions: Southeast (North Carolina, South Carolina, Georgia, Alabama), Delta (Mississippi, Tennessee, Missouri, Arkansas, Louisiana), Southern Plains (Texas, Oklahoma, New Mexico), and West (California, Arizona).

Potential Effects of Cotton Production on Water Quality

Water quality and cotton production share several general linkages. When agricultural chemicals are applied to cropland, some residues of a pesticide or its degradates may remain in the soil after plant uptake and subsequently leach to subsurface waters. Residues may also move to surface water by dissolving in runoff or adsorbing to sediment. Chemical or physical processes may transform residues into other products that also may affect the quality of water resources.

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The potential for fertilizers and pesticides to reach water bodies depends on a combination of factors. The chemical properties of the pesticides and fertilizers, soil characteristics and other geologic factors, rainfall, and application and management techniques all influence the likelihood that chemicals applied to cropland but not taken up by crops will leach into ground water or be washed away into lakes and streams.

When runoff from cropland reaches lakes, streams, and estuaries, the residues from nutrient and pesticide applications and sediments can contribute to water-quality problems. Nutrients, particularly nitrogen and phosphorus, promote algae growth and premature aging of lakes, streams, and estuaries (a process called eutrophication). Pesticide residues that reach surface water systems may also affect the health and vigor of freshwater and marine organisms. Suspended sediment impairs aquatic life by reducing sunlight, damages spawning grounds, and may be toxic to aquatic organisms.

The primary concern with agricultural chemicals in ground water is the possibility that exposure to dissolved materials in drinking water may pose a human health risk. A well-documented human health risk from nitrate contamination is infant methemoglobinemia, a condition where nitrates impair the ability of an infant's blood to carry oxygen (USDA, 1991). Other agricultural chemicals may also pose health risks when present in drinking water. However, the amount of risk posed to humans is uncertain (Conservation Foundation, 1987). The Environmental Protection Agency (EPA) recently completed a nationwide survey of drinking water wells, which showed that only 1.2 percent of community water systems and 2.4 percent of rural private domestic wells sampled in the survey contained nitrates at levels higher than EPA's recommended levels (EPA, 1990). The concentration of nitrates or pesticides in drinking water may be below levels at which acute health effects have been observed. The health risk associated with ingesting water containing traces of pesticides or nitrates at levels below those in which human health is considered endangered is poorly understood (Conservation Foundation, 1987).

The economic losses associated with impaired water quality, such as lost recreation opportunities or increased cost of drinking water, depend not only on the quality of the water but also on the number of consumers using the resource and its different uses. Efforts to reduce agriculture's effect on water quality may in turn lead to lower output or higher production costs and reduced farm income if farm practices are restricted. If technical and economic linkages between agricultural production, water quality, and the value that people place on clean water were well understood, policies to protect water quality on the basis of their relative benefits and costs could be evaluated. With such knowledge, policies could be designed that incorporate the economic tradeoffs of reducing losses from impaired water quality, while minimizing the adverse effects on farm income and commodity production.

We take a general approach in this study. We use the data on agricultural chemical use and management practices in cotton farming in conjunction with physical data on resource conditions to identify the likelihood that cotton farming may contribute to water-quality problems. Using several screening models, we characterize the surveyed cotton acreage based on the potential for chemicals and sediment to harm ground and surface water quality. We use this information as a starting point to target a set of input use and farming practice restrictions aimed at preventing agricultural pollution to areas showing the greatest environmental risk from cotton production. These pollution-preventing strategies are then evaluated for their environmental effectiveness and their economic effects on farmers through yield reduction and price changes.

Agricultural Chemical Use on Cotton Cropland

The Cotton Water Quality Survey (CWQS), conducted in the fall of 1989, gathered detailed data on agricultural chemical use, production practices, and resource conditions associated with cotton production. A stratified sample was taken to be representative of cotton cropland. The survey represents 10.5 million acres, about 99 percent of all cotton acreage planted in 1989 (fig. 1). The survey was field-based; that is, data on agricultural chemical use and resource characteristics are relevant for the sample field. Total sample size was 1,750 fields. A complete summary of all data collected in the survey is beyond the scope of this report. However, complete details on the data and collection methods are available from the authors on request. (See Crutchfield, 1990, and Crutchfield and others, 1991, for details.)

Cotton production is chemical-intensive, including the use of fertilizers, insecticides, defoliants, and herbicides. Herbicides and insecticides are applied to control weeds and pests. Growth regulators are applied to help produce uniformly sized plants. Defoliants are used to facilitate harvest by stripping the plant of leaves before the cotton bolls are picked.

Chemical fertilizers are an important part of the cotton production process. Fertilizers, such as nitrogen, phosphate, and potash, are applied in the fall, in the spring while the seedbed is being prepared, and during the growing season to enhance plant yield and quality. Nearly all the cotton farmers surveyed treated their fields at least once during the season. For the 14 States surveyed, 82 percent of cotton acres were treated with nitrogen, 60 percent with phosphate, and 42 percent with potash.

Herbicides are extensively used in cotton production to control weeds. Weeds reduce the cotton yield by competing for available light, moisture, and nutrients. Weeds also can reduce the quality and marketability of cotton lint (for instance, grasses can stain the lint during harvest). The field is usually tilled before planting to reduce grass and weed infestation. Both pre- and post-emergence herbicides are applied. For the 14 States surveyed, nearly 93 percent of the 1989 planted acreage received at least one treatment of herbicides. Nearly 100 percent of the acreage in the Southeast and Delta was treated with herbicides (fig. 2).

Cotton farmers face several insect pests, including cotton aphids, the boll weevil, pink bollworm, bollworm, and tobacco budworm. Insect problems are greatest in the Delta and the Southeast, and the least in the Southern Plains. The severity of the insect problem varies with a number of factors, including the amount of rainfall, irrigation, and patterns of crop rotation. Surveyed cotton producers reported using insecticides on 7.1 million acres (68 percent of the 10.5 million acres surveyed). The number of treatments averaged 4.7 per acre across those acres treated in the four regions.

Cotton farmers also use agrichemicals for growth regulation and foliage and disease control. Defoliants and desiccants are applied to cotton plants to aid the harvesting process as the bolls on the plants mature. Half of the surveyed cotton acreage was treated with defoliants and desiccants, mostly in the West, Southeast, and Southern Plains. Growth regulators are applied to cotton to help produce uniform plant sizes and to aid harvesting. Slightly more than one-third of all surveyed acres were treated with growth regulators, most frequently in the Southeast. Foliar fungicides are not widely used in cotton production. Of the surveyed acreage, only about 819,000 acres (8 percent) were treated with fungicides, mostly in the Delta States. (However, most cottonseed, and thus cotton acreage, is treated with fungicides prior to planting. Data on such treatments were not gathered as part of the 1989 CWQS.)

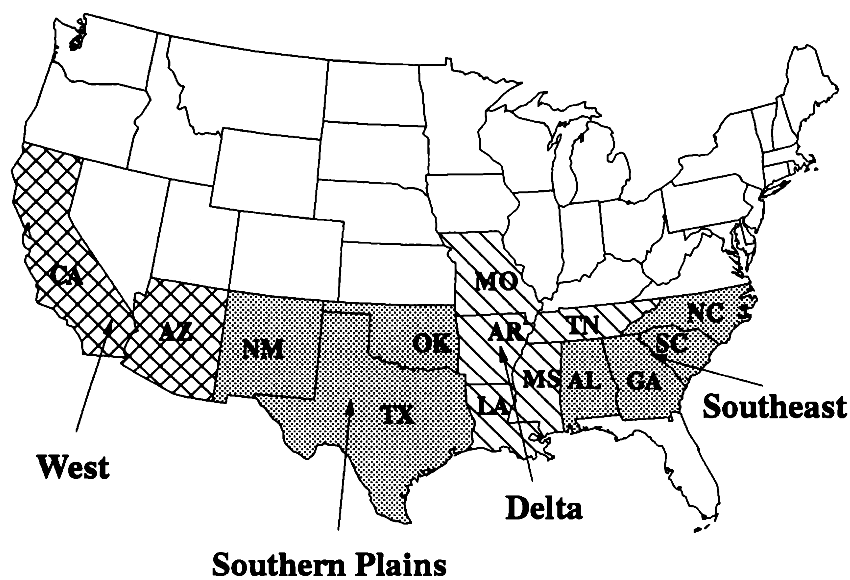
Soil Conservation on Cotton Cropland

Conserving soil is an important way to reduce agriculture's effects on surface water quality. Reducing soil erosion with practices such as conservation tillage, contour plowing, and grass waterways reduces movement of sediments and farm chemicals to nearby lakes and streams. However, soil conservation practices may also have a perverse effect on ground water quality. For example, conservation practices such as low-till or no-till tillage may increase the intensity of pesticide (particularly herbicide) use. This result may increase the vulnerability of underlying aquifers to leached pesticides.

Most cotton is produced under conventional tillage, where a moldboard or disk plow is used to turn the soil and incorporate most plant residue into the soil. Conservation tillage, including no-till, ridge-till, or mulch till, leaves more plant

Figure 1
Regions examined by the 1989 Cotton Water Quality Survey

The survey represents 10.5 million acres, about 99 percent of all cotton acreage planted in 1989.



residue on the field, and is used on only 9 percent of all cropland. Stalk destruction to reduce the number of overwintering pests eliminates residue on cotton fields, so leaving residue on the field to control erosion is not widespread. Other erosion control practices, such as terracing or contour plowing, are used in some regions, but none are in widespread use. Dry climate and flat topography make erosion control practices less necessary in the West.

Effects of Cotton Production on Water Quality

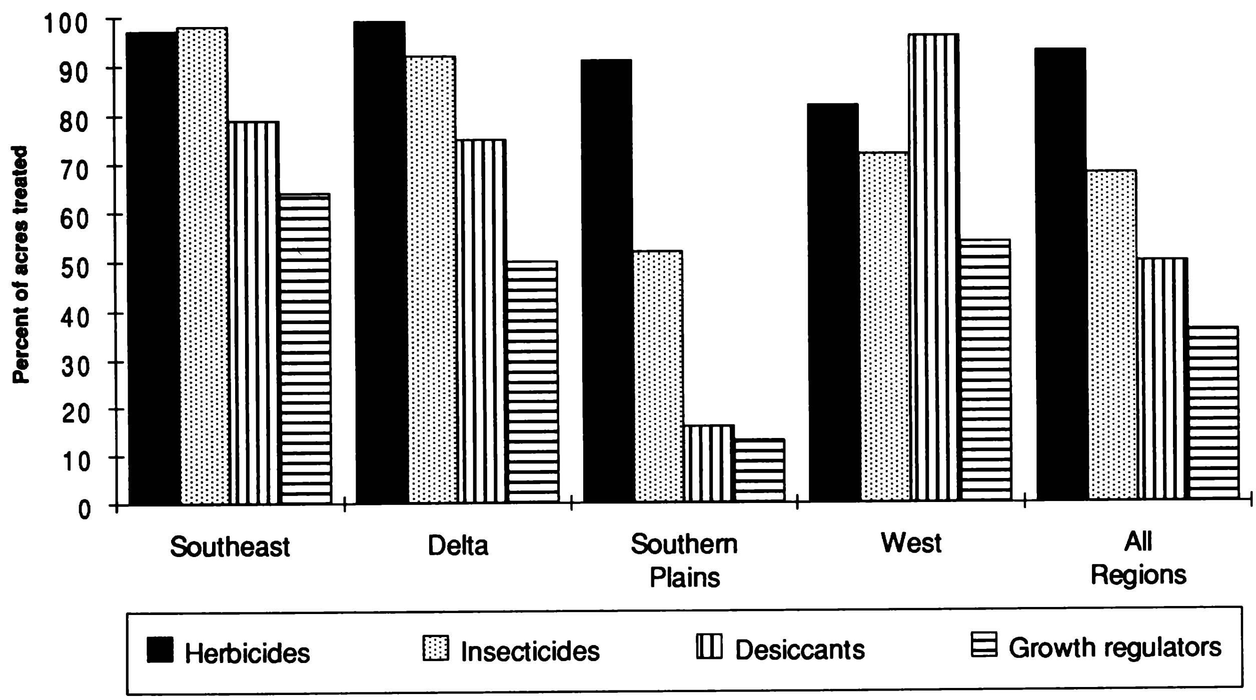
This section presents an initial assessment of some of the possible water-quality effects associated with production practices and chemical use on cotton. The analysis represents a first-cut approach at defining the possible extent of water-quality problems associated with cotton production. We use data on chemical use, resource conditions, and agricultural practices obtained from the survey as inputs to some simple screening and assessment models. The models were developed to characterize the surveyed acreage by its potential for off-farm water-quality effects. In some instances, we use models to estimate delivery of pollutants to water bodies and the possible effects of cotton production on ambient water quality. In other cases, particularly for pesticide leaching and runoff, we take a less definitive approach by characterizing the potential for water-quality degradation from cotton production rather than estimating actual pollutant flows or establishing direct linkages between cotton production and measures of water quality.

We define chemical loss potentials rather than directly estimating loadings. The scientific understanding of the relationships between agricultural production and off-farm water-quality effects is imperfect at best. Models are available that simulate the movement of chemical residuals and sediment from cropland to water bodies, but these models tend to be data-intensive and are site specific. As such, they are not particularly well suited to making national aggregate assessments of agricultural effects on water quality of the sort dealt with here, because the data required to run these models are not available from the survey.

We also face the additional constraint of estimating pollutant flows through time as well as through space, particularly for ground water quality. It may take years before agricultural chemicals applied to cropland leach into underground aquifers. Again, simulation models are available that can be applied on a site-by-site basis to estimate pollutant flows and ambient ground water quality over time, but they require significant amounts of hydrogeophysical and climate data on

Figure 2
Agrichemical use on cotton acreage, 1989.

Herbicides were the most widely used class of agricultural chemicals.



a site-specific basis. Since such detailed information was not available from the 1989 Cotton Water Quality Survey, we did not estimate actual chemical pollutant delivery to water bodies. Instead, we characterized surveyed cotton acreage on the basis of the "potential" for chemical leaching losses from cropland.

Additional USDA research is underway to estimate actual pollutant delivery and to make more explicit the linkages between agricultural production, chemical use, water-quality effects, and the economic damage associated with impaired water quality. The research summarized here should be viewed as a first step, one that defines the potential extent of the water-quality problem associated with agricultural production, identifies factors thought to contribute to the problem, and provides initial insight into possible policy options to diminish or prevent these adverse effects.

Surface Water Quality

Agriculture's effect on water quality of lakes, rivers, and streams is primarily driven by soil erosion and runoff from cropland. Using survey data, we calculated estimates of soil erosion as a first step in making the link between cotton production and off-farm surface water effects.

We used a model developed by Ribaudo (1986, 1989) that links soil erosion and off-site water-quality effects. This model consists of three stages that link soil erosion, movement of pollutants from field to waterway, and the physical effects on water quality.

Soil Erosion

The Universal Soil Loss Equation (USLE) was used to estimate soil erosion on surveyed cotton acreage. The survey instrument collected several variables of the USLE directly: LS (land slope factor), R factor (rainfall), and C factor (cropping). The K factor (erodibility) was obtained by linking soil classifications obtained by the survey with associated soil characteristics in the USDA-Soil Conservation Service (SCS) Soils V database. Survey data were used to calculate the P factor (practices). We calculated estimates of soil erosion for each sample point in the survey. Weighting factors calculated as part of the survey were used to aggregate individual estimates to State and regional bases.[1]

Table 1 presents estimates of soil erosion on surveyed cotton acreage. The average erosion rate on U.S. cotton is estimated at 5.4 tons per acre per year (tons/a/y). Erosion rates varied between 0.4 tons/a/y in California to 16.4 tons/a/y in Arkansas.

[1] Since the survey is based on a stratified sample of cotton acreage, weighting factors are associated with each sample point. The factors measure the contribution of the sample field to total surveyed acreage, and are used to aggregate from individual sample acreage to aggregate sample.

Surface Water Sediment Loadings

Using the procedure developed by Ribaudo (1989), we estimated soil erosion on cotton cropland and used it as input into a pollutant delivery model. The pollutant delivery model accounts for movements of soil and nutrients from the edge of the field to natural or constructed waterways. The amount of sediment that reaches a waterway depends on factors such as the distance, slope, and vegetation characteristics of the watershed.

The model is set up on a watershed (United States Geologic Survey Aggregated Subarea, or ASA) basis. Erosion data from survey sample points were distributed among ASA's, and estimates of soil erosion on cotton cropland were used to estimate pollutant loadings into surface waters. Table 1 presents estimates of the amount of sediment delivered to surface water bodies from erosion on cotton cropland in the 14 surveyed States. Sediment loadings are based on sediment delivery ratios estimated by Resources for the Future (RFF) (Gianessi, Peskin, and Puffer, 1985). Texas had the highest sediment loading, due to the large amount of cotton acreage in that State. The high per-acre rate of cropland erosion in Arkansas, however, means that the delivery of sediment to surface waters per cotton acre per year is higher in that State.

Surface Water Agrichemical Effects

Ribaudo's model accounts only for delivery of sediment to surface waters. Estimates of deliveries of pesticides and other agricultural chemicals are more difficult to develop. The model can be used to estimate nutrient delivery to water bodies, but not on a crop-specific basis. Estimates of nutrient loadings to surface water attributable solely to runoff from cotton cropland would have to be constructed using site-specific physical transport models. Ribaudo's model also does not calculate delivery of pesticides to surface waters. A screening procedure developed by Goss and Wauchope (1991), however, can be used to estimate the potential for applied pesticides to be removed from cropland dissolved in runoff and attached to sediment. Their methodology categorizes cropland by the potential for pesticides to move from the soil to surface waters.

The Goss and Wauchope procedure creates a qualitative index that describes the relative potential of pesticides put on cropland to leave the field. The physical properties of the soil and the chemical properties of the pesticides applied jointly determine the overall propensity of the pesticides to leave the field attached to soil particles (adsorption) or dissolved in runoff. Cropland is placed in one of three loss-potential categories. Potential 1 represents acreage with the highest potential for pesticides to leave the field. Potential 3 represents acreage with the lowest potential. Appendix A gives a full discussion of the screening model and loss-potential algorithms.

Table 1--Estimated soil erosion and sediment delivery to surface waters from cotton cropland, by State and region, 1989

Erosion rates on cotton cropland were highest in the Delta States.

State/region	Erosion rate	Total gross erosion	Total sediment delivered
	Tons/a/y[1]	-----*1,000 tons*-----	
Alabama	12.0	4,200	2,251
Arizona	2.6	624	278
Arkansas	16.4	10,004	5,624
California	.4	420	205
Georgia	5.0	1,350	444
Louisiana	8.3	5,354	3,017
Mississippi	8.6	9,030	5,095
Missouri	4.0	856	465
New Mexico	2.4	146	61
North Carolina	4.6	515	22
Oklahoma	5.0	1,900	928
South Carolina	8.0	960	408
Tennessee	10.5	4,732	2,592
Texas	3.1	14,260	6,77
Delta	10.1	29,976	16,793
Southeast	8.2	7,025	3,323
Southern Plains	3.2	16,306	7,761
West	.8	1,044	483
All regions	5.4	54,351	28,360

[1]Tons per acre per year.

Tables 2 and 3 present estimates of the proportion of cropland in each State and region that falls into the three defined pesticide loss-potential categories. A fourth category, called "Unknown," is also included to account for uses of agricultural chemicals not included in the Goss and Wauchope assessment procedure. The potential for pesticides applied to cropland to leave the field attached to soil particles is estimated in table 2, and the potential for pesticides to leave the field dissolved in runoff is estimated in table 3. A significant proportion (50 percent) of the total acreage for all the 14 States surveyed fell into the category of highest potential for pesticide loss through adsorption. A smaller share (26 percent) of the cropland showed a high potential for pesticide loss dissolved in runoff.

Ground Water Quality

The precise effects of agricultural chemical use on ground water quality are not as well understood as chemical effects on surface water. To measure the potential losses of pesticides to ground water, we used the methodology developed by Goss and Wauchope (1991) to categorize the likelihood that pesticides applied to cropland leach into ground water.

Potential Pesticide Leaching

We constructed leaching potential measures for each sample point using survey data on soil properties and information about the chemical properties of the pesticides applied. Weighting factors calculated as part of the survey were used to construct regional estimates of the amount of cotton cropland in each category of pesticide leaching potential. Table 4 presents these estimates. Cropland covered by the survey was given a loss-potential score ranging from "Potential 1" (highest probability of pesticide leaching) to "Potential 4" (virtually no probability of pesticide leaching). The results from our screening assessment show that acreage with a high potential for pesticide leaching is much less widespread than acreage with a high potential for loss to surface water. Although the leaching potential index is not directly comparable with surface water pesticide loss indexes, only 5 percent of the cropland fell into the highest leaching loss potential category. Thus, it appears that pesticide leaching to ground water from cotton production may not be a widespread problem. Of course, specific sites could experience serious pollution problems, depending on local conditions.[2]

Potential Nitrate Leaching

The Goss and Wauchope procedure does not address the possibility that nitrogen applied to cropland may result in nitrates leaching into ground water. We used a methodology developed by Williams and Kissell (1991) to measure the potential nitrate losses from cotton cropland. Their approach considers both annual and seasonal precipitation with soils information to construct an ordinal measure, called the Leaching Index, of the relative likelihood that nitrates will leach below the root zone. Appendix A also provides details of this procedure.

As with the pesticide-leaching measures, survey data were used to construct a nitrate-leaching index at each sample point. Using the overall potential loss scores at each sample point, we used weighting factors obtained in the survey to compute aggregate estimates of the acreage in each category. Table 5 shows the overall and regional breakdown of cropland by nitrate-leaching potential.

[2]For example, localized cases of ground water contamination may arise from improper mixing, loading, disposal, or storage of pesticides near wellheads. This may result in ground water contamination not caused by normal field application of chemicals.

Table 2--Estimated surface water vulnerability potential: Pesticides attached to sediment, by State and region, 1989

Cotton cropland with a high potential for pesticide losses attached to dissolved sediment is primarily in the Delta and Southern Plains States.

State	Potential 1[1]		Potential 2		Potential 3		Unknown	
	1,000 acres	*Percent*	*1,000 acres*	*Percent*	*1,000 acres*	*Percent*	*1,000 acres*	*Percent*
Alabama	19	5	125	36	6	2	200	57
Arizona	14	6	17	7	69	29	140	58
Arkansas	230	38	115	19	0	0	264	43
California	149	14	57	5	15	1	830	79
Georgia	0	0	7	3	243	90	20	8
Louisiana	217	34	145	22	0	0	283	44
Mississippi	398	38	185	18	7	1	460	44
Missouri	44	21	38	18	11	5	121	56
New Mexico	22	35	25	41	11	18	4	6
North Carolina	23	21	33	29	0	0	56	50
Oklahoma	258	68	50	13	14	4	57	15
South Carolina	31	26	19	16	15	13	54	45
Tennessee	194	43	74	16	0	0	187	41
Texas	3,503	76	558	12	38	1	500	11
Delta	1,084	36	557	19	18	1	1,315	44
Southeast	73	9	184	22	265	31	330	39
Southern Plains	3,783	75	634	13	63	1	561	11
West	163	13	74	6	83	6	970	75
All regions	5,103	50	1,449	14	429	4	3,177	31

[1]Potential 1 cropland is most vulnerable to pesticide loss, while potential 3 has little or no likelihood of pesticide loss.

Overall, about half of the surveyed acreage was rated as having a "high" or "excessive" nitrate-leaching potential. This acreage was concentrated primarily in the Delta and West. In contrast, the Southern Plains showed generally moderate or low potential for nitrate leaching.

Both the pesticide and nitrate screening procedures establish only an indication of potential chemical losses from the root zone and do not quantify or estimate the actual losses of pesticides or nitrates to ground water. Actual leaching to ground water occurs only to the extent that the chemicals applied fail to be taken up by the plant or fail to bind to soil particles in the upper layers of soils. Nitrate and pesticide leaching are site specific; hot spots and less vulnerable areas will occur within each region, and aggregate measures such as those used here can mask considerable variation in leaching potential within each region.

These estimates should not be used to make inferences about any contamination of ground waters. While it is potentially possible to simulate the movement of chemicals past the root zone using process models, the behavior of chemicals in lower depths of the soil profile (the vadose, unsaturated, and saturated zones) is subject to considerable uncertainty. Information about the quality of the ground water resources themselves is not readily available on a comprehensive basis, and any attempt to link above-ground chemical use, resource conditions, and measures of ground water quality based on data from the CWQS would be highly speculative at best. Accordingly, the results of the assessment procedures used here should be viewed as only a general indicator of the potential for pesticides and nitrogen applied to cotton cropland to leach past the root zone.

In summary, there appears to be fairly widespread potential for cotton production to adversely affect water quality. Given the attention placed in recent years on ground water contamination from agricultural pesticides, it is interesting to note that the **potential** for pesticides applied to cotton cropland to eventually reach ground water supplies appears to be less widespread than the potential for nitrate leaching or for pesticides to reach surface waters through runoff and soil erosion. Such a conclusion will influence the extent to which policies aimed at preventing or reducing pollution affect cotton farmers and consumers.

Table 3--Estimated surface water vulnerability potential: Pesticides dissolved in runoff, by State and region, 1989

About 26 percent of all cotton acreage in the survey was given the highest relative potential for losses of pesticides dissolved in runoff.

State	Potential 1[1]		Potential 2		Potential 3		Unknown	
	1,000 acres	*Percent*	*1,000 acres*	*Percent*	*1,000 acres*	*Percent*	*1,000 acres*	*Percent*
Alabama	31	9	119	34	0	0	200	57
Arizona	14	6	49	20	37	15	140	58
Arkansas	251	41	75	12	20	3	264	43
California	72	7	108	10	39	4	830	79
Georgia	7	3	0	0	243	90	20	8
Louisiana	217	34	145	22	0	0	283	44
Mississippi	419	40	172	16	0	0	460	44
Missouri	33	15	60	28	0	0	121	56
New Mexico	29	47	29	47	0	0	4	6
North Carolina	23	21	9	8	23	21	56	50
Oklahoma	50	13	258	68	14	4	57	15
South Carolina	15	13	43	35	8	6	54	45
Tennessee	228	50	40	9	0	0	187	41
Texas	1,259	27	2,681	58	160	3	500	11
Delta	1,147	39	492	17	20	1	1,315	44
Southeast	77	9	171	20	274	32	330	39
Southern Plains	1,338	27	2,967	59	174	3	561	11
West	87	7	157	12	76	6	970	
All regions	2,649	26	3,787	37	545	5	3,177	31

[1]Potential 1 cropland is most vulnerable to pesticide loss, while potential 3 has little or no likelihood of pesticide loss.

Analysis of Pollution-Reducing Production Changes on Cotton Cropland

Herbicides, insecticides, fertilizers, and other agricultural chemicals are widely used in cotton production. There may be some danger that these chemicals may cause environmental problems off the farm. However, restricting chemical use on cotton cropland in an attempt to protect water quality can hurt the yields and profitability of cotton farmers. Restrictions on chemical use should aim for a suitable level of environmental protection at a minimum economic cost to producers.

In this section, we assess the likely consequences of restricting cotton farmers' chemical applications to eliminate the use of pesticides, herbicides, and other chemicals most likely to impair water quality. We explore two broad classes of pollution-prevention strategies: (1) banning the application of chemicals considered the most likely to leave the field through leaching, adsorption, or runoff on all cotton acreage and (2) banning these chemicals on acreage identified by our screening analysis as having the greatest potential for off-field losses of agricultural chemicals.

The objective of this analysis is twofold. First, we estimate the likely effect on yields and returns arising from modifying production practices for environmental reasons. Second, we characterize the change in distribution of environmental vulnerability across cotton acreage after certain high-risk chemicals are removed from the choice of inputs.

Estimates of Cotton Production Relationships

We began by building a model of cotton production, which was estimated using data from the survey. The objective was to quantify the relationship among farming practices, chemical input use, and yields obtained by cotton farmers. The model enabled us to evaluate the changes in yields and, therefore, farm revenues as production practices and input choices are restricted for environmental reasons.

Our modeling approach was influenced by the nature of the available data. The 1989 CWQS randomly sampled acres in cotton-producing areas for information on chemical use, production practices, and resource data at

Table 4--Estimated ground water vulnerability potential: Pesticide leaching, by State and region, 1989

Only 5 percent of surveyed cotton cropland in all regions was given the highest relative potential for pesticides to leach.

State	Potential 1[1]		Potential 2		Potential 3		Potential 4		Unknown	
	1,000 acres	*Percent*	*1,000 acres*	*Percent*	*1,000 acres*	*Percent*	*1,000 acres*	*Percent*	*1,000 acres*	*Percent*
Alabama	63	18	81	23	50	14	0	0	156	45
Arizona	26	11	49	20	26	11	3	1	137	57
Arkansas	61	10	115	19	264	43	47	8	122	20
California	6	1	21	2	46	4	147	14	830	79
Georgia	0	0	88	33	169	63	0	0	14	5
Louisiana	51	8	58	9	326	51	174	27	36	6
Mississippi	69	7	124	12	542	52	89	8	226	22
Missouri	44	21	33	15	77	36	22	10	38	18
New Mexico	16	26	20	32	22	35	0	0	4	6
North Carolina	0	0	9	8	47	42	19	17	37	33
Oklahoma	7	2	72	19	201	53	43	11	57	15
South Carolina	31	26	19	16	43	35	0	0	27	23
Tennessee	13	3	147	32	147	32	47	10	100	22
Texas	105	2	1,325	29	1,678	36	1,087	24	405	9
Delta	238	8	477	16	1,357	46	379	13	523	18
Southeast	93	11	198	23	308	36	19	2	234	27
Southern Plains	128	3	1,417	28	1,900	38	1,130	22	466	9
West	32	2	70	5	71	6	150	12	967	75
All regions	491	5	2,161	21	3,636	36	1,679	17	2,191	22

[1]Potential 1 cropland is most vulnerable to pesticide loss, while potential 4 has little or no likelihood of pesticide loss.

each sample point. Each observation gave an estimate of input and yield relevant to that particular acre. Data from the CWQS can be used to estimate input-output relationships. However, certain economic factors cannot be included on a per-acre basis (specifically, allocation of capital and other fixed factors within a farm enterprise). The estimated production relationship is of a partial nature, and does not capture some substitution possibilities, such as output-output substitution or land-capital substitution.

We assumed that the per-acre yield of a cotton field depends on several generic classes of inputs:

$$Y = Y(C,W,R,Z), \qquad (1)$$

where:

Y = Yield (bales/acre)
C = Applied chemicals
W = Water (irrigation)
R = Site-specific measures of soil quality
Z = Farm management choice variables.

A variety of functional forms have been used to estimate yields functions. Examples commonly used in empirical studies include the quadratic, Mitscherlich-Baule, and Von Liebig type functions (Cerrato and Blackmer, 1990; Frank and others, 1990). We used a modified version of the quadratic function which was used by Huang and Hansen (1991) to estimate cotton yield responses to nitrogen application using CWQS data. We modeled cotton production in the following manner:

$$\begin{aligned} Y = {} & a_0 + a_1{*}N + a_2{*}N^2 + a_3{*}W + a_4{*}W^2 + \\ & a_5{*}W{*}N + b_1{*}WTRCAP + b_2{*}SLOPE + \\ & b_3{*}PERM + b_4{*}ORGN + b_5{*}EROSION + \\ & c_1{*}IRR + c_2{*}EC + c_3{*}CT + c_4{*}ARP + \\ & c_5{*}HERB + c_6{*}INSECT + c_7{*}SEED \end{aligned} \qquad (2)$$

where:

N = Nitrogen applied (pounds/acre)
W = Water applied, including estimated rainfall and irrigation water (acre feet/acre)
WTRCAP = Water-holding capacity of the soil

Table 5--Estimated ground water vulnerability potential: Nitrate leaching, by region, 1989

Cotton cropland in the Southern Plains showed less potential vulnerability to leaching nitrates than in other regions.

Region	Excessive vulnerability		High vulnerability		Moderate vulnerability		Low vulnerability	
	1,000 acres	*Percent*	*1,000 acres*	*Percent*	*1,000 acres*	*Percent*	*1,000 acres*	*Percent*
Alabama	244	70	44	13	63	18	0	0
Arizona	180	75	23	10	37	15	0	0
Arkansas	203	33	312	51	95	16	0	0
California	241	23	497	47	266	25	45	4
Georgia	88	33	14	5	169	63	0	0
Louisiana	246	38	333	52	65	10	0	0
Mississippi	281	27	645	61	124	12	0	0
Missouri	11	5	88	41	115	54	0	0
New Mexico	29	47	16	26	14	24	2	3
North Carolina	56	50	33	29	23	21	0	0
Oklahoma	29	8	79	21	122	32	151	40
South Carolina	74	61	31	26	15	13	0	0
Tennessee	80	18	368	81	7	1	0	0
Texas	153	3	171	4	712	15	3,564	77
Delta	822	27	1,746	58.8	46	14	0	0
Southeast	461	54	121	14	270	32	0	0
Southern Plains	210	4	265	5	848	17	2,717	74
West	421	33	520	40	304	23	45	3
All regions	1,915	18	2,653	26	1,827	18	3,761	37

SLOPE = Slope of the surveyed field
PERM = Permeability of the soil
ORGN = Organic matter content of the soil
EROSION = Erosion rate (calculated using the Universal Soil Loss Equation)
IRR = Dummy variable for irrigation (1 if field is irrigated)
EC = Dummy variable for erosion control (1 if field had erosion control practices installed)
CT = Dummy variable for conventional tillage (1 = conventional, 0 = reduced or no-till)
ARP = Dummy variable for cotton acreage reduction program (1 if farmer participated in cotton ARP in 1989)
HERB = Herbicides, measured by total pounds active ingredient applied per acre.
INSECT = Insecticides, measured by total pounds active ingredient applied per acre.
SEED = Seeding rate, pounds/acre.

This particular specification was used to capture anticipated nonlinearity in nitrogen's effect on yield, as well as possible interaction between applied nitrogen and water. The dummy variables for erosion control and conventional tillage were included to permit us to estimate the yield effects of the most likely approaches to reducing cropland runoff to protect surface water quality.

Estimation Results

The production function (equation 2) was estimated using 1989 CWQS data. After observations with refusals and missing or inappropriate values were discarded (such as a reported yield of zero) 1,109 observations were available. Equation 2 was estimated using the nonlinear least squares (SYSNLIN) procedures in the Statistical Analysis System (SAS). Results are presented in table 6.

Overall, the estimated equation showed a good fit: adjusted R^2 was 0.57, which is good for cross-sectional data such as these. Four of 19 estimated parameters were not significant at the usual confidence levels of 95 percent. These variables (water capacity, slope, erosion rate, and pounds of herbicides applied) were not used in the simulation procedure to estimate how yield would change if nitrogen use were restricted or conservation measures applied, so they do not influence the simulation results reported below.

Table 6--Production function estimation results

Nonlinear OLS summary of residual errors

SSE: 373.12528	MSE 0.34232	Root MSE: 0.58508
R-Square: 0.5811	Adj R-Sq: 0.5742	

Nonlinear OLS parameter estimates

Parameter	Estimate	Std Err	Approx. |T| Ratio	Approx. Prob>|T|	Label
A0*	1.257840	0.16540	7.60	0.0001	
A1*	0.00488686	0.0005629	8.68	0.0001	Nitrogen
A2*	-9.88097E-6	1.58692E-6	-6.23	0.0001	Nitrogen squared
A3*	0.400762	0.03825	10.48	0.0001	Water
A4*	-0.041023	0.0049209	-8.34	0.0001	Water squared
A5*	0.00038533	0.0001234	3.12	0.0018	Water*nitrogen
B1	0.033203	0.63308	0.05	0.9582	Water capacity
B2	-0.021952	0.01428	-1.54	0.1245	Slope
B3*	-0.00070464	0.0002873	-2.45	0.0143	R Factor
B4*	-0.021758	0.0088866	-2.45	0.0145	Soil permeability
B5*	-0.068709	0.02864	-2.40	0.0166	Organic matter content
B6	0.00037546	0.0009511	0.39	0.6931	Erosion from USLE
C1*	0.119543	0.05640	2.12	0.0343	Irrigation dummy
C2*	-0.097359	0.04774	-2.04	0.0417	Erosion control dummy
C3*	0.138306	0.06862	2.02	0.0441	Conventional tillage dummy
C4*	-0.128535	0.06343	-2.03	0.0430	Participation in cotton ARP
C5**	0.013009	0.0079039	1.65	0.1000	Herbicides (lbs AI***/acre)
C6*	0.044826	0.0080004	5.60	0.0001	Insecticides (lbs AI/acre)
C7*	-0.016397	0.0043422	-3.78	0.0002	Seed

*Significant at a 95-percent confidence level.
**Significant at a 90-percent confidence level.
***Active ingredient

Cotton yields showed decreasing returns in nitrogen and water, although the second-order term for nitrogen was fairly small. Our dummy variables for farming practices had the expected signs: other things being equal, irrigated farmers had higher per-acre yields, farmers applying erosion control practices had lower yields, and farmers using conventional tillage practices had higher per-acre yields than those using no-till or low-till practices.

Yield Effects of Modified Production Practices and Reduced Nitrogen Use

The estimated production function was used to evaluate the effect of environmental policies aimed at protecting water quality. Three specific scenarios were used to reflect these policies: (1) reduce soil erosion and runoff by requiring installation of erosion control practices on highly erodible land, (2) reduce soil erosion and runoff by banning conventional tillage (that is, requiring some form of low-till or no-till) on highly erodible land, and (3) mandated reduction of nitrogen fertilizer application to 100 or 75 pounds per acre on land considered vulnerable to nitrate leaching.

For all three scenarios, the estimated regression coefficients were used with actual survey data to predict a baseline estimated yield. Then, a second input data set was created, where the relevant independent variable (conventional tillage dummy, erosion control dummy, or nitrogen application rate) was modified according to whether the land was erodible (scenarios 1 and 2) or considered to have a high or excessive nitrate leaching potential, based on the screening models described above. This was done for each sample point in the survey, and results aggregated to State, regional, and national levels using expansion factors built into the survey.[3] Predicted yields for each scenario were compared with baseline estimates and percentage yield losses were calculated.

The results are presented in table 7. For the four scenarios considered, overall yield losses (based on total harvested acreage) ranged from 1 percent (requiring erosion control on

[3]Predicted yields under the baseline scenario were lower than actual yields, since there were several hundred observations with missing values of one or more independent variables. The contribution of those sample points to total acreage and estimated total yield were thereby dropped from the calculations.

Table 7--Yield effects of modified production practices and reduced nitrogen use, 1989

Limiting nitrogen to 75 pounds per acre on vulnerable cropland had the greatest effect on yields.

State/region	Base Yield	Require erosion control		Require conservation tillage		Limit N to 100 lbs/acre		Limit N to 75 lbs/acre	
		New yield	Change	New yield	Change	New yield	Change	New yield	Change
	---*1,000 bales*----		*Percent*	*1,000 bales*	*Percent*	*1,000 bales*	*Percent*	*1,000 bales*	*Percent*
Alabama	300	296	-1	291	-3	298	-1	290	-3
Arizona	590	583	-1	581	-2	536	-9	514	-13
Arkansas	689	688	0	687	0	682	-1	660	-4
California	1,902	1,899	0	1,898	0	1,831	-4	1,784	-6
Georgia	149	149	0	149	0	149	0	147	-1
Louisiana	707	704	0	703	-1	690	-2	670	-5
Mississippi	1,033	1,029	0	1,021	-1	1,002	-3	961	-7
Missouri	151	151	0	151	0	149	-1	145	-4
New Mexico	114	113	-1	112	-2	112	-1	111	-2
North Carolina	64	63	-1	63	-1	60	-6	58	-9
Oklahoma	237	235	-1	234	-1	236	0	234	-2
South Carolina	139	139	0	138	0	134	-3	127	-8
Tennessee	484	476	-2	465	-4	482	0	471	-3
Texas	3,892	3,793	-3	3,693	-5	3,876	0	3,866	-1
Delta	3,063	3,046	-1	3,026	-1	3,004	-2	2,907	-5
Southeast	651	647	-1	641	-2	640	-2	622	-4
Southern Plains	4,243	4,141	-2	4,039	-5	4,225	0	4,211	-1
West	2,492	2,483	0	2,479	-1	2,366	-5	2,298	-8
All regions	10,449	10,317	-1	10,185	-3	10,235	-2	10,037	-4

[1]1,000 bales. Base yields are less than actual yields from the CWQS since observations having missing values of right-hand-side variables are deleted.

erodible land) to nearly 4 percent (limit nitrogen to 75 lbs/acre on land vulnerable to nitrate leaching). Some variation across States and regions is evident, which is to be expected since the distribution of erodible and vulnerable acreage is not uniform across regions. Also, not all farmers face input use restrictions: for the entire surveyed acreage, only 15.7 percent of cropland was considered highly erodible and did not already have erosion control practices in place. Nationwide, 22 percent of cropland was highly erodible and was farmed with conventional tillage. Nitrogen restrictions of 100 pounds/acre or 75 pounds/acre on vulnerable land applied to about 17 percent and 28 percent of all acreage. As a consequence, the yield losses and economic effects will not apply to all farmers and all regions.

Yield Effects of Restrictions on Pesticide Use

We take an alternative approach to estimating the effects of restricting input use. We would ideally model agricultural chemical use by estimating a cost or production function based on existing data using an econometric or programming approach. The effects of either restricting quantities or imposing taxes could then be simulated, yielding not only changes in output but changes in input mix as well (for instance, substitution of labor or land for restricted agricultural chemicals).

This approach is not feasible or particularly useful for analyzing the types of issues of concern here, for a variety of reasons. First, the range of input choices regarding agricultural chemicals used in cotton production is too broad: the survey listed 9 desiccants or defoliants, 8 fungicides, 3 growth regulators, 30 herbicides, and 52 insecticides. Collinearity problems and loss of degrees of freedom (not all chemicals are used by all farmers) would preclude listing all 102 possible chemical choices as right-hand-side variables in a production or cost function. When constructing our simple yield function, therefore, we aggregated pesticides into distinct categories: herbicides and insecticides.

However, treating pesticides aggregated by classes does not help to assess the types of input restrictions that are imposed to protect water quality. EPA policies aimed at pollution prevention are targeted at specific chemicals, often in specific areas or in specific uses. Farmers are not likely to be faced with restrictions on "insecticide" or "herbicide" use; rather, water-quality policies take the form of restricting individual chemicals, identified in part on their expected propensity to leach or enter surface water bodies.[4] We need to determine the ability of farmers to substitute pesticides and the associated effects on yields and costs on a chemical-by-chemical basis.

As an alternative to explicitly incorporating chemical-specific input substitution possibilities in our econometric model, we drew upon expert opinion from participants in a cotton chemical use assessment study to understand how losses of specific chemicals would affect cotton production and input use. Experts estimated the pesticide materials, control practice, and acreage treated for each reported target pest on a State-by-State basis (USDA, Agricultural Research Service, various years). The assessment also included three critical pieces of information: a listing of alternative chemicals if the pesticide in question were "lost," an estimate of potential yield losses if substitute chemicals were used, and an estimate of potential yield losses if the substitute chemicals were also "lost" or not available. The last element is crucial because if one pesticide were banned due to its susceptibility to leaching, a good substitute may also be highly leachable and, therefore, not available to farmers under a policy to restrict use of leachable chemicals. Thus, we need estimates of yield losses if alternatives to regulated chemicals are not available.

We used this expert information about substitution possibilities and potential yield losses to construct estimates of chemical use, vulnerability, and yield per acre on the survey data under a number of different chemical regulation scenarios. A synthetic data set was created that contained estimates of per-acre yields and chemical use, based on the information in our expert opinion surveys on likely chemical substitutions and yield losses.

A critical assumption here is that all other factors of production were held constant in the presence of chemical-use restraints. This, of course, does not accommodate the possibility of farmers changing other inputs (land, labor, crop rotations, and so on) in response to restrictions on chemical applications. We make this arbitrary assumption because we lack quantitative information about substitution of nonchemical for chemical inputs on a chemical-specific basis, either from our model of cotton production or expert opinion. In defense of this assumption, however, we noted in our analysis of qualitative information from the expert opinion surveys that alternatives to restricted chemicals were available, in most cases, so farmers could protect yields somewhat by making marginal adjustments in their choice of chemical mixes applied to cotton acreage. Since farmers do make such adjustments, the bias introduced by not explicitly accounting for nonchemical alternatives to banned pesticides may be minor.

To assess the effects of pollution-prevention strategies, we first drew up a list of likely candidates for chemical restrictions: chemicals listed in the SCS/ARS Pesticide Properties Database (Goss and Wauchope, 1991) as having "large" potential for loss to surface waters through adsorption or runoff, or "large" potential for leaching. At each sample point on the CWQS, a computer simulation model examined the range of chemicals used on that sample field. If, at that sample point, a chemical was used that had a "large" potential for leaching, adsorption, or runoff, the expert opinion database was queried to determine potential alternatives to the pesticide in question. Alternative chemicals not considered environmentally risky (that is, "large" potential for leaching or runoff) were substituted for the chemical in question at that sample point, with estimates of application rates and number of treatments based on the target pest and recommendations drawn from the expert database. A new estimate of the per-acre yield was also constructed, based on expert opinion of the likely yield effects if the chemical in question were "lost." If no alternatives to the chemical in question were available (either none listed in the expert database, or none available with "low" or "moderate" loss potentials), then the chemical in question was deleted from the input data set and the sample point yield estimate adjusted to reflect the "no alternatives available" adjustment factor from the expert opinion database.

This procedure was used to evaluate two possible pollution-prevention strategies: banning the use of environmentally suspect chemicals on all cropland, and banning the use of such chemicals on cropland judged to be most likely to be vulnerable to chemical leaching or runoff via the screening models (that is, "potential 1" acreage). Within each strategy, four alternatives were considered, reflecting different water-quality issues: banning chemicals most likely to leach, banning chemicals most likely to attach to sediment and leave the field via soil erosion, banning chemicals most likely to dissolve in cropland runoff, and a combination of all three. Eight different runs of the simulation program were used, calculating predicted agricultural chemical use and yields under each of the different policy options.

[4]For example, EPA's recently released "Pesticides and Ground-Water Strategy" calls on the States to restrict or ban pesticide use on a chemical-by-chemical basis, when concentrations of chemicals detected in ground water reach a certain percentage of maximum allowable levels. These restrictions would most likely be for a defined geographic region (such as a wellhead or critical recharge zone) or for specific uses or application methods rather than wholesale, statewide or nationwide use restrictions.

Table 8 presents the predicted yields from surveyed acreage from the eight different policy options considered.[5] The estimated percentage reductions were as high as a 14-percent loss (ban all risky chemicals on all cropland), but most were smaller or nearly zero. Targeting chemical restrictions to apply only to vulnerable cropland reduces the estimated yield losses by about two-thirds.

Environmental Effects of Modified Production Practices: Erosion Control and Conservation Tillage

The suspended sediment model developed by Ribaudo was used to estimate the potential improvements in surface water quality if erosion on cotton acreage were reduced. This involved a two-step procedure. First, potential reductions in erosion on cotton cropland were estimated for the two scenarios described above: installing conservation practices on highly erodible acres and reducing erosion on cotton acreage via conservation tillage. The reductions in erosion were then fed into the model to predict the changes in concentrations of suspended sediment for regions covered by the survey.

The first scenario assumed that farmers adopted conservation tillage practices on land considered "highly erodible" under the standard used for the conservation compliance provisions of the Food Security Act of 1985. We compared erosion occurring in the base case (current patterns of conservation tillage use) and the erosion that would occur if reduced tillage practices were applied on "highly erodible" cotton acreage. The results indicate that erosion would decline by about 14 percent.[6] Average erosion rates would decline from 5.4 tons/a/y to 4.6 tons/a/y (table 9).

The second scenario assumed that operators farming highly erodible land installed erosion control practices, such as terracing, contour farming, and strip cropping. Erosion rates were calculated on the assumption that such practices were adopted on highly erodible land. The results indicate that erosion would be reduced by about 19 percent. Average erosion rates would decline from 5.4 tons/a/y to 4.3 tons/a/y. Erosion rates in several States, notably Arkansas and Alabama, remained high, despite the installation of conservation practices on highly erodible land.[7]

The changes in erosion rates from these two scenarios were then used to estimate the expected changes in surface water quality. A baseline level of suspended sediment was calculated from 1982-83 monitoring data. The effects of reduced erosion from switching away from conventional tillage and from installing erosion control practices were measured by the changes in concentrations of sediment in these watersheds. Table 10 reports results for the watersheds in the survey States.

The results indicate that reducing erosion on cotton acreage alone would not greatly improve surface water quality regarding sediment loadings, even if the erosion reductions on cotton acreage were substantial. The reason is that there are many sources of sediment in surface water besides cotton cropland, and the contribution from cotton in any one region is not a large proportion of total sediment reaching the surface water systems.

Environmental Effects of Chemical Restrictions

Estimating the effect of reduced nitrogen use on nitrate leaching and ground water quality is considerably more complex than estimating changes in erosion and sediment delivery. Estimation of nitrate leaching is site-specific, and would require point-by-point application of process models to calculate losses below the root zone. Such an activity, while worthwhile, is beyond the scope of this study.

Eleven pesticides were identified in the SCS/ARS database as having a "large" leaching potential. If those chemicals were no longer available to farmers, the acreage falling into the "potential 1" class (highest relative vulnerability) would decline from about 491,000 acres (5 percent of all cropland) to 157,000 acres, or 1 percent (table 11). However, the acreage falling in the "Unknown" category more than doubles, from 2.2 million acres to 4.8 million acres, or nearly 47 percent of the 10.2 million acres surveyed, because farmers would be substituting chemicals whose leaching potential is unknown. Qualitatively similar results were found if restrictions on leachable chemicals were applied only on cropland classified as "potential 1" in the base case.

Sixteen chemicals covered by the survey were classified as having a "large" potential to dissolve in cropland runoff. Restricting those chemicals, either globally or on vulnerable acreage alone, would cut the amount of cropland classified as

[5]Since the survey is field-based, yield estimates for each sample point reflect the number of bales per harvested acre at that point. Weighting factors developed as part of the survey are used to aggregate up to national yield estimates on all 10.2 million acres.

[6]Not all acres in the survey were assessed. Unassessed acres were deleted and the results were adjusted to reflect the full base acreage. Since assessment was uneven between States, comparison among States may not be representative.

[7]This scenario assumes that farmers harvesting on highly erodible lands would, in fact, install conservation measures on that cropland. In practice, farmers may choose to forgo participation in USDA programs rather than install such practices if the costs of conservation outweigh the benefits of program participation.

Table 8--Yield effects of restricting chemicals with high leaching, adsorption, or runoff potential, 1989

When chemical restrictions are limited to vulnerable cropland the overall yield loss is smaller.

State/region	Base yield	Ban leachers		Ban highly adsorbing chemicals		Ban highly soluble chemicals		Ban all "risky" chemicals	
		New yield	Change	New yield	Change	New yield	Change	New yield	Change
	----1,000 bales---		*Percent*	*1,000 bales*	*Percent*	*1,000 bales*	*Percent*	*1,000 bales*	*Percent*
Restrict chemicals on ALL cropland:									
Alabama	372	341	-8	237	-36	372	0	227	-39
Arizona	531	531	0	407	-23	514	-3	402	-24
Arkansas	862	862	0	842	-2	862	0	842	-2
California	2,753	2,719	-1	2,489	-10	2,701	-2	2,473	-10
Georgia	344	337	-2	161	-53	344	0	160	-53
Louisiana	908	904	0	592	-35	859	-5	583	-36
Mississippi	1,427	1,413	-1	1,427	0	1,427	0	1,413	-1
Missouri	253	251	-1	252	0	253	0	250	-1
New Mexico	107	106	-1	107	0	105	-2	105	-2
North Carolina	145	139	-4	117	-19	145	0	117	-19
Oklahoma	304	304	0	250	-18	304	0	250	-18
South Carolina	156	153	-2	143	-8	156	0	140	-10
Tennessee	413	410	-1	344	-17	413	0	344	-17
Texas	2,708	2,690	-1	2,350	-13	2,680	-1	2,344	-13
Delta	3,864	3,840	-1	3,458	-11	3,815	-1	3,432	-11
Southeast	1,017	970	-5	657	-35	1,017	0	644	-37
Southern Plains	3,120	3,101	-1	2,708	-13	3,090	-1	2,699	-13
West	3,284	3,249	-1	2,896	-12	3,216	-2	2,875	-12
All regions	11,284	11,160	-1	9,719	-14	11,137	-1	9,651	-14
Restrict chemicals on VULNERABLE cropland only:									
Alabama	372	370	-1	365	-2	372	0	363	-2
Arizona	531	531	0	527	-1	530	0	523	-1
Arkansas	862	862	0	852	-1	862	0	852	-1
California	2,753	2,752	0	2,707	-2	2,749	0	2,705	-2
Georgia	344	344	0	344	0	344	0	344	0
Louisiana	908	907	0	804	-11	897	-1	802	-12
Mississippi	1,427	1,426	0	1,427	0	1,427	0	1,426	0
Missouri	253	253	0	253	0	253	0	253	0
New Mexico	107	107	0	107	0	105	-2	105	-2
North Carolina	145	145	0	136	-6	145	0	136	-6
Oklahoma	304	304	0	268	-12	304	0	268	-12
South Carolina	156	155	0	152	-2	156	0	152	-3
Tennessee	413	413	0	381	-8	413	0	381	-8
Texas	2,708	2,705	0	2,428	-10	2,688	-1	2,413	-11
Delta	3,864	3,862	0	3,718	-4	3,853	0	3,714	-4
Southeast	1,017	1,014	0	997	-2	1,017	0	995	-2
Southern Plains	3,120	3,116	0	2,803	-10	3,097	-1	2,787	-11
West	3,284	3,282	0	3,235	-1	3,279	0	3,228	-2
All regions	11,284	11,275	0	10,753	-5	11,246	0	10,724	-5

Table 9--Potential erosion reduction on cotton cropland by State and region, 1989

Applying erosion control measures to cotton cropland could reduce erosion, particularly in the Delta and Southeast.

State/region	Base erosion		With conservation tillage practice		With erosion control practice	
	Rate	Amount	Rate	Amount	Rate	Amount
	Tons/a/y	*Tons*[1]	*Tons/a/y*	*Tons*[1]	*Tons/a/y*	*Tons*[1]
Alabama	12.0	4,200	10.2	3,570	9.4	3,290
Arizona	12.6	624	1.7	408	1.5	360
Arkansas	16.4	10,004	15.3	9,333	14.8	9,028
California	0.4	420	0.4	420	0.4	420
Georgia	5.0	1,350	5.0	1,350	5.0	1,350
Louisiana	8.3	5,354	8.1	5,224	7.9	5,096
Mississippi	8.6	9,030	7.9	8,295	7.2	7,560
Missouri	4.0	856	4.0	856	4.0	856
New Mexico	2.4	146	2.1	128	2.0	122
North Carolina	4.6	515	4.3	482	4.2	470
Oklahoma	5.0	1,900	4.8	1,824	4.7	1,786
South Carolina	8.0	960	7.8	936	4.8	936
Tennessee	10.5	4,732	8.8	4,004	7.6	3,458
Texas	3.1	14,260	2.2	10,120	2.0	9,200
Delta	10.1	29,976	7.5	27,712	8.7	25,998
Southeast	8.2	7,025	7.4	6,338	7.1	6,046
Southern Plains	3.2	16,306	2.4	12,072	2.2	11,108
West	0.8	1,044	0.6	828	0.6	780
All regions	5.4	54,351	4.6	46,950	4.3	43,932

[1]Tons of erosion.

"potential 1" by about 23 percent, from 2.6 million acres to about 2.1 million (table 12). Little change is seen in the distribution of relative leaching or adsorbed loss potentials due to banning soluble chemicals.

Chemicals with a large potential for adsorbed loss constituted the largest number (34) of target pesticides. Banning the use of these chemicals would reduce the amount of cropland in the highest adsorbed loss potential category by about 60 percent, to about 1.8 million acres (table 13). This policy would also slightly decrease the share of cropland at highest risk for dissolved runoff loss, but increase marginally the amount of cropland at risk for chemical leaching.

The largest environmental effect was seen when all chemicals subject to leaching, adsorption, or runoff loss were banned. In this case, the acreage classified as "potential 1" for leaching fell from 491,000 to 336,000 acres (table 11), "potential 1" acreage for dissolved runoff loss fell from 2.6 to 1.3 million acres (table 12), and "potential 1" acreage for adsorbed loss fell from 5.1 to 1.6 million acres (table 13). In terms of overall environmental effects, however, these figures may overstate the potential for protecting water resources from chemical contamination somewhat. In all cases, there was a fairly significant increase in the amount of acreage classified as "unknown."

One interesting conclusion emerges when considering the difference between global chemical restrictions, which apply to all cropland, and targeted restrictions. If pollution-prevention benefits are reflected by decreases in the percentage of cropland falling in the "potential 1" category, the targeted policy of restricting chemical use only on vulnerable acreage performs nearly as well as global pesticide restrictions. The additional environmental benefits of extending use restrictions to all cropland over and above those attained by imposing restrictions only on vulnerable cropland appear to be small. However, the differences in overall yield effects between targeted and nontargeted policies are greater. As seen in table 8, extending chemical-

Table 10--Potential water-quality improvements from erosion control by ASA,[1] 1989

Reducing erosion on cotton cropland may not improve surface water quality substantially because cotton acreage is only a small part of all sources of such runoff.

ASA[1]	Base case	Conservation tillage practices on HEL[2]		Erosion control practices on HEL	
	Sediment concentration	Sediment concentration	Change	Sediment concentration	Change
		Milligrams per liter			
301	28.80	28.76	0.04	28.74	0.06
302	54.31	54.29	.02	54.29	.02
303	24.91	24.91	.00	24.91	.00
304	29.60	29.60	.00	29.60	.00
306	18.74	18.74	.00	18.74	.00
307	28.69	28.58	.11	28.51	.18
308	36.37	36.12	.25	35.89	.48
309	51.19	51.05	.14	50.92	.27
602	14.37	13.62	.75	13.32	1.05
801	136.58	136.01	.57	135.71	.87
802	214.85	214.20	.65	213.71	1.15
1105	243.51	243.51	.00	243.51	.00
1106	663.66	662.40	1.26	662.22	1.43
1107	222.67	222.67	.00	222.67	.00
1201	53.04	53.04	.00	53.04	.00
1202	102.87	102.49	.38	102.17	.70
1203	401.73	397.91	3.82	397.32	4.41
1204	80.03	73.55	6.48	71.98	8.05
1205	138.61	138.61	.00	138.61	.00
1302	2,052.50	2,052.46	.04	2,052.44	.06
1303	403.40	403.40	.00	403.40	.00
1304	504.34	504.17	.17	504.10	.24
1305	345.50	344.71	.79	343.82	1.68
1502	1,125.02	1,125.02	.00	1,125.02	.00
1503	890.85	885.94	4.91	884.77	6.19
1803	30.63	30.54	.09	30.51	.12
1806	617.67	617.67	.00	617.67	.00

[1]ASA = Aggregated Sub-Area, as defined by the U.S. Geological Survey, U.S. Dept. of Interior.
[2]HEL = Highly erodible land.

use restrictions to all cropland increases the yield loss over the more narrowly targeted scenarios. This result reinforces the efficiency arguments in favor of targeted pollution-prevention strategies. Imposing a ban on environmentally risky chemicals on all cotton acreage yields only marginal benefits in terms of environmental protection compared with the targeted policy, but would cut harvest by an additional 1 million bales (assuming acreage remains constant).

Economic Effects of Environmental Policies

Environmental policies aimed at preventing water pollution will have an economic effect on cotton farmers and society as a whole. Restrictions on input use may raise production costs. Prices and support payments may be affected if alternative environmental policies reduce cotton harvests. The increased costs of production and the increased prices paid by consumers after the imposition of environmental controls represent a net economic cost to society for the gain in water quality.

Table 11--Distribution of cotton acreage by ground water pesticide leaching potential, 1989

High ground water vulnerability is not widespread, so targeting chemical restrictions to acreage vulnerable to leaching does not substantially affect ground water risk.

Policy	Potential 1 (most vulnerable)		Potential 2		Potential 3		Potential 4 (least vulnerable)		Unknown	
	1,000 acres	*Percent*	*1,000 acres*	*Percent*	*1,000 acres*	*Percent*	*1,000 acres*	*Percent*	*1,000 acres*	*Percent*
Restrict chemicals on all cropland:										
Base	491	5	2,161	21	3,636	36	1,679	17	2,191	22
Ban leachers	157	1	1,950	19	3,966	39	1,776	17	2,308	22
Ban adsorbers	674	6	1,180	11	2,424	23	1,186	11	4,693	46
Ban solubles	399	3	1,990	19	3,622	35	1,960	19	2,186	21
All "risky" chemicals	336	3	909	8	2,594	25	1,483	14	4,835	47
Restrict chemicals on vulnerable cropland:										
Base	491	5	2,161	21	3,636	36	1,679	17	2,191	22
Ban leachers	157	1	2,296	22	3,768	37	1,690	16	2,249	22
Ban adsorbers	698	6	1,231	12	2,471	24	1,194	11	4,563	44
Ban solubles	402	3	1,981	19	3,619	35	1,957	19	2,197	21
All "risky" chemicals	288	2	1,198	11	2,717	26	1,326	13	4,627	45

Table 12--Distribution of cotton acreage by surface water dissolved runoff loss potential, 1989

The distribution of cropland across vulnerability classes was nearly the same when restrictions applied to potential 1 acreage as when highly soluble chemicals were banned on all acreage.

Policy	Potential 1 (most vulnerable)		Potential 2		Potential 3 (least vulnerable)		Unknown	
	1,000 acres	*Percent*	*1,000 acres*	*Percent*	*1,000 acres*	*Percent*	*1,000 acres*	*Percent*
Restrict chemicals on all cropland:								
Base	2,649	26	3,786	37	544	5	3,176	31
Ban leachers	2,528	24	3,562	35	559	5	3,506	34
Ban adsorbers	2,039	20	1,517	14	921	9	5,679	55
Ban solubles	2,103	20	4,239	41	558	5	3,262	32
All "risky" chemicals	1,261	12	1,741	17	1,017	10	6,137	60
Restrict chemicals on vulnerable cropland:								
Base	2,649	26	3,786	37	544	5	3,176	31
Ban leachers	2,713	26	3,549	34	559	5	3,335	32
Ban adsorbers	2,087	20	1,562	15	958	9	5,549	54
Ban solubles	2,101	20	4,213	41	556	5	3,286	32
All "risky" chemicals	1,629	16	1,715	16	997	9	5,186	51

Table 13--Distribution of cotton acreage by surface water adsorbed loss potential, 1989

Restricting use of chemicals likely to adsorb can significantly reduce the potential for chemical loss through soil erosion.

Policy	Potential 1 (most vulnerable)		Potential 2		Potential 3 (least vulnerable)		Unknown	
	1,000 acres	*Percent*	*1,000 acres*	*Percent*	*1,000 acres*	*Percent*	*1,000 acres*	*Percent*
Restrict chemicals on all cropland:								
Base	5,103	50	1,449	14	429	4	3,177	31
Ban leachers	4,950	48	1,310	12	389	3	3,506	34
Ban adsorbers	1,848	18	2,114	20	515	5	5,679	55
Ban solubles	5,303	52	1,141	11	450	4	3,262	32
All "risky" chemicals	1,593	15	1,919	18	507	4	6,138	60
Restrict chemicals on vulnerable cropland:								
Base	5,103	50	1,449	14	429	4	3,177	31
Ban leachers	5,153	50	1,279	12	396	3	3,335	32
Ban adsorbers	1,827	17	2,236	22	543	5	5,548	54
Ban solubles	5,303	52	1,112	10	456	4	3,286	32
All "risky" chemicals	2,049	20	1,734	17	557	5	5,816	57

On the other hand, society values clean water. Reducing sedimentation or other impairments in lakes and streams can generate significant benefits in recreational and other uses (Clark and others, 1985; Ribaudo, 1986). If the value placed by society on the gain in water quality exceeds the cost to consumers and producers of reducing the pollutant loadings, net social welfare increases.

Valuing economic effects on the production side is fairly straightforward. When yield is reduced, market prices may increase, causing shifts in production and consumption. We use the U.S. Agricultural Resources Model (USARM) to quantify the expected price, production, and output effects of several policies for pollution prevention. Estimated changes in prices and incomes under the alternative environmental policies are used to measure the effects these policies may have on the agricultural sector.

Valuing the environmental benefits of improving or protecting water quality is more problematic. Ribaudo (1989) has developed a model that links changes in onfarm practices to off-farm benefits due to water-quality improvements from reduced soil erosion. We use this model to value the improvement in surface water quality associated with reducing erosion and installing conservation measures on highly erodible cotton cropland.

The economic benefits of protecting ground water quality are less clear. It is beyond the scope of this study to establish a clear linkage between onfarm chemical use and quality of ground water resources. Process models could be applied at each sample point to measure chemical losses below the root zone, but we would still need additional information on ambient ground water conditions to measure the change in resource quality and, eventually, consumer willingness to pay for improved water quality. We do not have enough detailed information about ground water quality and its relationship to production practices on cotton cropland to make any but the most general statements about the value of preventing ground water contamination. Accordingly, we used a cost-effectiveness approach to highlight the economic consequences of pollution prevention. We compare the economic effects of different levels of agricultural chemical-use restrictions to prevent leaching, and use differential effects of these policies to highlight the opportunity costs of choosing different levels of protection for ground water resources.

Economic Effects on Cotton Producers

We defined 12 different scenarios for preventing water quality degradation from cotton production (fig. 3). The estimated yield effects of alternative policies reported in tables 7 and 8 formed the starting point for our analysis. For each scenario, we used the USARM to calculate the expected effects on the agricultural sector.

USARM is a partial equilibrium, comparative static programming model that simulates competitive equilibria in the presence of deficiency payment programs. It is designed to study the likely effects of changes in resource constraints,

Figure 3
Pollution-prevention strategies analyzed by the USARM model

Pollution-prevention strategies included production restrictions on vulnerable acreage as well as on all harvested cropland.

Policy	Target resource: Surface water	Target resource: Ground water
1. Require erosion control on highly erodible land	X	
2. Require conservation tillage on highly erodible land	X	
3. Limit nitrogen to 100 lbs/acre on vulnerable cropland	X	X
4. Limit nitrogen to 75 lbs/acre on vulnerable cropland	X	X
5. Ban leachable chemicals on all land		X
6. Ban leachable chemicals on vulnerable land		X
7. Ban highly adsorbing chemicals on all land	X	
8. Ban highly adsorbing chemicals on vulnerable land	X	
9. Ban highly soluble chemicals on all land	X	
10. Ban highly soluble chemicals on vulnerable land	X	
11. Ban all "risky" chemicals on all land	X	X
12. Ban all "risky" chemicals on vulnerable land	X	X

prices, and policies on the location, production, and prices of the principal crops, agricultural resource use, and program participation. USARM produces medium-term estimates of these effects rather than long-term forecasts.

The objective function is quadratic in both revenues and cost. Negatively sloped product demand curves allow output prices to be endogenous at the national level. Positively sloped supply curves impose decreasing returns with rising production of a given activity. The production function is characterized by Leontief technology.

USARM encompasses 9 crops (barley, corn, cotton, hay, oats, rice, sorghum, soybeans, and wheat) and land in the Conservation Reserve Program (CRP) across 23 regions (17 Western States plus the 6 eastern farm production regions). The primary decision variables are: (1) crop selection and acreage allocation, (2) production method (irrigated or dryland), and (3) participation and nonparticipation in Federal commodity programs.

To simulate the effect of environmental restrictions on cotton production, the State-by-State percentage changes in yield for each of the scenarios reported in tables 7 and 8 are used as constraints on the USARM. That is, yield is restricted in each State to reflect the estimated yield reductions associated with each scenario. The model then solves for equilibrium values of the decision variables by shifting acreage and crop mix across States and regions until the objective function is maximized.

Table 14 presents selected results from the 12 policy scenarios (see fig. 3) analyzed with the USARM. The policy that had the largest yield decline (banning all "risky" chemicals on all cropland, scenario 11) showed the most pronounced effect on prices: a 14.5-percent yield decline led to a 31-percent increase in cotton prices. For most of the other scenarios, the effect on prices and incomes of cotton farmers was fairly small.

The direction of change in cotton farmers' income depended on the policy in question. The USARM uses linear demand functions for commodities; therefore, as harvests change, the direction of the change in income will depend on the position of the magnitude of the movement from the initial point along a linear demand curve. Small decreases in yields will lead to declines in net income; for larger harvest reductions, we move into the inelastic portion of the demand curve and income rises. For small changes in yields, revenues to cotton farms dropped between $1 million and $33 million. When more drastic yield reductions were imposed, price increases offset the decline in output, and income rose by more than $400 million. For three scenarios (reduce nitrogen to 75 pounds/acre (scenario 4), ban adsorbing chemicals on all cropland (scenario 7), and ban all "risky" chemicals nationwide (scenario 11)) the increase in prices and incomes led to a shift out of the cotton program: acreage not enrolled in the program rose 4-17 percent.

There will be distributional effects associated with each scenario. Only those farmers who use "risky" chemicals on vulnerable acreage, or who apply high rates of nitrogen, or whose cropland is erosive and is farmed with conventional tillage will be affected by these restrictions. Other farmers, for whom the constraint is not binding, may enjoy some transient benefits in the form of higher prices for their harvests.[8] A complete analysis of this phenomenon is not possible, since USARM by its design imposes uniform yield

[8] The USARM treats all cropland within a State uniformly, so it cannot distinguish between vulnerable/erosive cropland and cropland not subject to input constraints.

Table 14--Aggregate economic effects of alternative environmental policies, 1989

Targeting production restrictions to vulnerable acreage limits the increase in cotton prices and reduces the economic cost.

Policy[1]	Acreage	Change	Price	Change	Yield	Change	Income	Change	Change in consumers' surplus	Deadweight loss
	1,000 acres	*Pct.*	*Cents/lb*	*Pct.*	*1,000 bales*	*Pct.*	*$1,000*	*Pct.*	*$1,000*	*$1,000*
Base	10,032	---	0.637	---	11,284	---	3,450,196	---	---	---
1	10,001	-0.3	0.642	0.8	11,137	-1.3	3,431,978	-0.5	26,905	176
2	9,964	-0.7	0.647	1.6	11,002	-2.5	3,416,781	-1.0	53,486	677
3	10,004	-0.3	0.650	2.0	11,047	-2.1	3,446,664	-0.1	69,673	739
4	9,951	-0.8	0.676	6.1	10,844	-3.9	3,518,661	2.0	207,118	4,118
5	10,011	-0.2	0.642	0.8	11,160	-1.1	3,439,066	-0.3	26,933	149
6	10,030	0.0	0.637	0.0	11,275	-0.1	3,447,444	-0.1	0	0
7	8,988	-10.4	0.830	30.3	9,719	-13.9	3,872,050	12.2	972,859	72,491
8	9,775	-2.6	0.677	6.3	10,753	-4.7	3,494,295	1.3	211,555	5,098
9	10,032	0.0	0.644	1.1	11,137	-1.3	3,442,669	-0.2	37,667	247
10	10,023	-0.1	0.639	0.3	11,246	-0.3	3,449,373	0.0	10,814	18
11	8,975	-10.5	0.834	30.9	9,651	-14.5	3,863,488	12.0	989,807	77,208
12	9,764	-2.7	0.679	6.6	10,724	-5.0	3,495,166	1.3	221,841	5,645

[1]See figure 3 for explanation of the 12 strategies.

reductions across an entire production region. At present, we lack the level of temporal or spatial disaggregation in our models to be able to trace through all the distributive effects of these policies.

Consumers of cotton products will see higher prices if harvests fall. This will mean a loss of consumer surplus, part of which takes the form of a transfer to farmers, who receive higher incomes. For example, assume a linear demand curve for cotton (as is the case with USARM). For scenario 11, which shows an increase in income to cotton producers from $3.4 billion to $3.9 billion, there is a loss of consumer surplus of $990 million, for an overall welfare cost (deadweight loss) of about $77 million (table 14). Welfare costs for most of the other scenarios would be much smaller, but still must be considered in evaluating the overall economic effect of production restrictions.

Water-Quality Benefits

For two scenarios (installation of erosion control measures (scenario 1) and conservation tillage (scenario 2)) we estimated the economic benefits of reduced erosion on cotton acreage to several different categories of water uses: recreational fishing, navigation, water storage, irrigation ditches, roadside ditches, water treatment, municipal and industrial water use, and stream cooling. The procedures for estimating benefits incorporated the physical, chemical, hydrologic, and economic links between the movement of soil and chemicals on the field and the effects on downstream water users.

Using data from Clark and others (1985) and Ribaudo (1986) we estimated the benefits per ton of soil erosion reduction for navigation, water storage, irrigation and roadside ditches, municipal and industrial water use, and stream cooling in each region. The reductions in erosion, estimated for each scenario and reported in table 9, were then used to calculate total benefits in these categories.

We estimated the effects of improved water quality on recreational fishing activity with a fishing participation model (Ribaudo and Piper, 1991). The model was estimated with recreational data from the U.S. Fish and Wildlife Service's 1980 National Survey of Hunting, Fishing, and Wildlife-Associated Recreation and water quality from the U.S. Geological Survey's National Stream Quality Accounting Network (NASQUAN). The model predicts changes in the number of people fishing and in the number of days they fished when regional water quality changes. Watershed-level water-quality changes from table 10 were used to predict changes in recreational fishing and the economic value of the increase in the recreational activity.

Table 15--Economic benefits from improving water quality by reducing soil erosion on cotton cropland, 1989

Off-farm water-quality benefits from erosion control and conservation tillage were greatest in the Southern Plains States.

Region[1]	Erosion control on HEL[2]			Conservation tillage practices on HEL		
	Benefits	Acres treated	Benefits per acre	Benefits	Acres treated	Benefits per acre
	$1,000	*1,000 acres*	*Dollars/acre*	*$1,000*	*1,000 acres*	*Dollars/acre*
Appalachian	638	86	7.43	1,103	139	7.91
Corn Belt	0	0	0.00	0	0	0.00
Delta	2,929	91	32.33	5,158	132	39.15
Lake States	0	0	0.00	0	0	0.00
Mountain	6,176	98	62.85	7,639	100	76.34
Northeast	0	0	0.00	0	0	0.00
Northern Plains	0	0	0.00	0	0	0.00
Pacific	0	39	0.00	0	39	0.00
Southeast	916	57	16.00	1,309	105	12.42
Southern Plains	6,823	1,222	5.58	8,379	1,696	4.94
All regions	17,482	1,593	10.97	23,588	2,211	10.67

[1] USDA Farm Production Regions, which differ from the regions defined elsewhere in this report for the CWQS. Estimation of benefit measures by CWQS region are not possible because the model used to estimate benefits cannot be used at a State-level basis.
[2] Highly Erodible Land.

A model of water treatment costs developed by Holmes (1988) helped us estimate changes in the costs of municipal water treatment from reductions in turbidity. The model specifies water treatment costs as a function of turbidity, the amount of water treated, and the costs of other inputs. We assumed that water quality is a perfect substitute with other turbidity-reducing inputs in the treatment process, and that the change in treatment costs does not affect the output of treated water. Benefits, therefore, equal the reduction in the costs of treating water (Freeman, 1982). Water-quality changes expected with the erosion-reduction scenarios were fed into this model to predict the benefits of reduced water treatment costs.

Table 15 shows the estimated water-quality benefits associated with the two erosion reduction scenarios. Estimated benefits range from $17.5-$23.6 million, with most of the benefits accruing to the Delta, Mountain (Arizona and New Mexico), and Southern Plains regions. Table 15 also shows the estimated dollar benefits per acre treated. The average benefit per acre of cropland treated is more than $10 per acre, and ranges from a low of $5 per acre in the Southern Plains to $76 per acre in the Mountain States for installing erosion control measures. In all regions, payments of up to $5 per acre for these conservation practices on cotton cropland through some form of cost-sharing or other financial assistance would generate off-farm water-quality benefits in excess of costs.

Conclusions

The most widespread potential water-quality problems from cotton production are possible nitrate leaching and losses of pesticides to surface waters. Efforts to prevent these types of pollution by limiting nitrogen fertilizer applications or restricting use of soluble pesticides are expected to have some economic effects by reducing yields and raising cotton prices. Other policies to prevent less prevalent pollution problems (leaching pesticides, for example) exhibited a much smaller change in prices, yields, and cotton farmers' income. When the off-farm benefits of improved water quality from erosion control are considered, the economic benefits from improving water quality are likely to be less than the cost to farmers or society of installing erosion control practices on highly erodible cropland.

Although our ability to quantify the benefits of preventing ground water pollution is less developed than our ability to measure the benefits of surface water quality improvement, the results of this study do highlight the importance of targeting pollution-prevention programs to attain the most cost-effective environmental protection strategies. Applying chemical-use restrictions only on acreage classified as susceptible to water-quality problems achieves nearly the same level of reduction in overall vulnerability as when chemical restrictions are applied to all acreage. By targeting chemical-use restrictions, yield losses are reduced by over 1 million bales and smaller increases in cotton prices result.

The data and analytic methods used in this study have some limitations. Our screening and assessment procedures present only a general characterization of the eventual environmental effects of cotton farming. Since environmental problems, particularly ground water leaching, are location-specific, aggregate measures (the kind we used) of leaching, runoff, or erosion potential inevitably mask considerable localized variability. Our characterization of substitution possibilities regarding agricultural chemicals, based on expert opinion, may overstate or understate the true substitution possibilities. Since we do not presently have data on ground water quality at a level of detail sufficient to establish a link between chemical use and eventual costs to consumers of impaired ground water quality, we compare policies to reduce or prevent leaching on the basis of cost effectiveness, rather than on the ultimate welfare to users of protecting ground water quality. Additional research into using process models to estimate chemical leaching and changes in water quality, in conjunction with studies on consumers' willingness to pay for reduced exposure to chemicals in drinking water, could improve our estimate of the benefits of preventing ground water pollution.

Cotton is only one of many agricultural products whose production can affect environmental quality. Reducing erosion or chemical use on cotton farms alone may not improve water quality significantly if other crops within a given area also contribute substantial pollutant flows to water resources. In addition, any policies to prevent pollution, either through voluntary adoption of new management practices or regulations restricting input use, will likely apply to several crops. ERS research now underway will assess the environmental and economic effects of pollution-prevention strategies on a more comprehensive scale.

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Appendix A: Assessment of Potential Vulnerability to Pesticide and Nitrate Losses to Ground and Surface Water

Pesticide Loss Potential

We used the methodology proposed by Goss and Wauchope (1991) to measure the potential losses of pesticides to ground water and surface water. They have developed a screening procedure to evaluate the potential loss of pesticides from soil that accounts for both the chemical properties of the pesticides and the physical properties of the soils. Their assessment procedure provides a classification scheme to categorize the likelihood that pesticides applied to cropland will leach into ground water or run off into surface waters. Based on this procedure, we classified observations in the cotton survey according to the potential for pesticides applied to this cropland to leave the root zone and enter water bodies.

Figure A-1 describes the assessment procedure. Two ordinal measures are developed that are jointly used to determine overall pesticide leaching or runoff potential: (1) a loss potential derived from the physical properties of the soil to which the pesticides are applied, and (2) a loss potential based on the chemical properties of the individual pesticides.

Soil-Leaching Potential

Many soil characteristics influence the environmental fate of chemicals applied to cropland. Factors thought to influence potential leaching of pesticides below the root zone include soil depth, the organic matter content of the soil, surface texture, subsurface texture, and the hydrologic properties of the soil. The screening procedure employs an algorithm to create an index of relative leaching potential based on four characteristics felt to be the most influential in determining pesticide losses: organic matter content of the surface horizon, the depth of the horizon, the soil erodibility (K factor), and the hydrologic classification (fig. A-2).

For each sample point in the CWQS, data for these four physical characteristics were obtained for the relevant soil type from the USDA-SCS Soils V database. Each sample point was then assigned a qualitative soil-leaching potential score based on these characteristics: high, intermediate, low, and very low. Using expansion factors based on the survey sample design, regional and national estimates of cotton acreage falling into each category were then calculated. The results are presented in table A-1.

Soil Adsorption Loss and Runoff Potential

Pesticides applied to cropland may reach surface waters in two ways. The chemicals may dissolve in surface water runoff, or adsorb to sediment and move to surface waters through soil erosion. Whether pesticides applied to cotton acreage leave the field dissolved in runoff or adsorbed to soil particles depends, in part, on the physical characteristics of the soil. Two measures were developed to categorize soils by their relative potential for losses to surface waters. A soil adsorption index was constructed based on the hydrologic properties and the soil K factor at each sample point. Similarly, a soil runoff solution potential index was calculated based on the hydrologic grouping of the soil at the sample point (fig. A-2). As with the leaching potential score, regional and national estimates of acreage in each category were made. These are also reported in table A-1.

Chemical-Leaching Potential

The chemical properties of individual pesticides also play a large role in determining whether chemical residues will leach below the root zone. The assessment procedure uses an algorithm based on the Ground Water Ubiquity Score (GUS) developed by Gustafson (1989) to classify pesticides according to their propensity to leach. A leaching potential score was developed for each chemical reported in the survey, based on the reported persistence in soil (half life), partition coefficient between soil organic carbon and water (Koc), and the solubility of the active ingredient in the pesticide. Categories were defined as large, medium, small, and extra small (fig. A-3).

Chemical Surface Loss Potential

Each chemical used on cotton production was characterized by its relative propensity to leave the site either dissolved in runoff or attached to sediment. Two indexes were constructed: the pesticide adsorption index describes the tendency of pesticides to adhere to soil particles, and the pesticide runoff solution index categorizes each chemical according to its tendency to dissolve in runoff. Both indices are based on the solubility, the organic-partitioning component, and the half life of the active ingredient of the pesticide (fig. A-3).

Estimates of Sample Point Chemical Loss Potentials

The Goss and Wauchope methodology is designed only to categorize the relative loss potential for single chemicals. We faced an additional complicating factor since, for many sample points, several different pesticides were used. Cotton producers use a variety of chemicals for insect, weed, and foliage control. The simple methodology described here is not designed to account for interactions among multiple chemicals applied to a particular parcel of cropland.

To simplify the assessment procedure, while retaining the essential elements of the Goss and Wauchope methodology, the properties of the chemicals applied at each sample point were analyzed to determine the predominant properties of the pesticides used. For each sample point, the leaching, adsorption, and runoff solution indexes were calculated for all chemicals. Reported application rates (estimated application rates in the case of herbicides) were used to derive an estimate of total chemical application by chemical loss class (high, intermediate, low, or very low), for leachability, adsorption potential, and runoff solution potential (table A-2).

Each sample point was then assigned a leachability, adsorption, or runoff solution score based on the predominant chemical class used at that sample point. For example, when total pounds of "high-leaching" chemicals applied (measured by pounds of active ingredient applied) exceeded applications of chemicals in other leachability classes, the sample point was assigned an aggregate leaching potential score of "high." Similarly, for those sample points where the largest amount of chemicals fell into the "low runoff solution potential" category, a score of "low" was used to characterize the runoff solution potential for the sample point as a whole, and so on.

For some chemicals used on cotton production, estimates of leaching, adsorption, and runoff solution loss potentials were not available. In those cases, an additional score of "unknown" was used. Results by region are reported in table A-3.

Determination of Overall Loss Potential

The overall pesticide loss potential was determined by the interaction of loss potentials defined by soil characteristics and by chemical properties. Each sample point was assigned an overall potential loss rating (fig. A-4). Categories are defined in relative terms, indicating the relative expectation of pesticide losses by taking into account soil and chemical properties. For example, if a sample point showed a large pesticide-leaching potential and an intermediate soil-leaching potential, then it was given a "potential 1" rating. However, a combination of high soil leaching potential with a small pesticide-leaching potential is given a lower relative ranking, called "potential 2." A potential 1 category has a higher likelihood of pesticide losses to water bodies than potential 2, and potential 2 has a higher expectation of pesticide losses than potential 3, and so forth.

Nitrate-Leaching Potential

The screening procedure used to estimate the potential for nitrates to leach below the root zone was developed by Williams and Kissell (1991). The procedure calculates several indices:

- A percolation index, which is a function of the soil hydrologic group and annual precipitation (P):

Hydrologic group	Percolation index
A	$(P-10.28)^2/(P+15.43)$
B	$(P-15.05)^2/(P+22.57)$
C	$(P-19.53)^2/(P+29.29)$
D	$(P-22.67)^2/(P+34.00)$

- A seasonal index, based on annual precipitation and seasonal precipitation (October-March, PW)

$$SI = (2*PW/P)^{1/3}$$

- A leaching index:

$$LI = PI * SI$$

- A leaching severity index, based on LI:

If LI is:	Leaching severity index is:
0-5	Low
5-10	Moderate
10-20	High
Above 20	Excessive

Figure A-1--Assessment procedure to measure vulnerability to pesticide leaching and losses to surface water

1. For each sample point in the survey, calculate loss potential based on *soil characteristics*:

   Soil-leaching loss potential: High, Intermediate, Low, or Very Low
   Soil adsorbed runoff loss potential: High, Intermediate, or Low
   Soil runoff solution loss potential: High, Intermediate, or Low

2. For each pesticide applied at each sample point in the survey, calculate loss potential based on *chemical properties*.

   Pesticide-leaching loss potential: Large, Medium, Small, or Extra Small
   Pesticide adsorbed runoff loss potential: Large, Medium, or Small
   Pesticide runoff solution loss potential: Large, Medium, or Small

3. For sample points for which more than one pesticide was used, determine the leaching potential of the predominant chemicals. Assign an overall loss potential based on the total pounds of pesticide applied.

4. For all sample points, assign an overall loss potential based on the conjunction of loss potential based on soil properties and loss potential based on chemical properties.

5. Using weighting factors obtained from the survey, expand sample points to achieve State, regional, and national estimates of cropland falling within each loss potential category.

Figure A-2--Procedures used to estimate pesticide loss potentials based on soil properties

1. Algorithm used to calculate soil-leaching potential

A soil has a *HIGH* leaching potential if:
Hydrologic group = A and organic matter times horizon depth <= 30, or
Hydrologic group = B and organic matter times horizon depth <= 9 and K factor <= 0.48, or
Hydrologic group = B and organic matter times horizon depth <= 15 and K factor <= 0.26.

A soil has a *LOW* leaching potential if:
Hydrologic group = B and organic matter times horizon depth >= 35 and K factor >= 0.40, or
Hydrologic group = B and organic matter times horizon depth >= 45 and K factor <= 0.20, or
Hydrologic group = C and organic matter times horizon depth <= 10 and K factor <= 0.28, or
Hydrologic group = C and organic matter times horizon depth >= 10.

A soil has a *VERY LOW* leaching potential if:
Hydrologic group = D.

2. Algorithm used to estimate soil adsorbed runoff potential

A soil has a *HIGH* adsorbed runoff potential if:
Hydrologic group = C and K factor > 0.21, or
Hydrologic group = D and K factor > 0.10.

A soil has a *LOW* adsorbed runoff potential if:
Hydrologic group = A or
Hydrologic group = B and K factor <= 0.10, or
Hydrologic group = C and K factor <= 0.07, or
Hydrologic group = D and K factor >= 0.05.

A soil has an *INTERMEDIATE* adsorbed runoff potential in all other cases.

3. Algorithm used to estimate soil runoff solution potential

A soil has a *HIGH* runoff solution potential if:
Hydrologic group = C, or
Hydrologic group = D.

A soil has a *LOW* runoff solution potential if:
Hydrologic group = A.

A soil has an *INTERMEDIATE* runoff solution potential if:
Hydrologic group = B.

Table A-1--Potential for pesticide losses from leaching, adsorption, or runoff based on soil properties, 1989

Soils vulnerable to surface water chemical losses are more widespread than are soils vulnerable to leaching pesticides.

Region	High		Intermediate		Low		Very low	
	1,000 acres	*Percent*	*1,000 acres*	*Percent*	*1,000 acres*	*Percent*	*1,000 acres*	*Percent*
Soil-leaching potential:								
Delta	271	9	740	25	1,222	41	741	25
Southeast	236	38	409	48	110	13	6	1
Southern Plains	1,764	35	1,760	35	557	11	960	19
West	335	26	456	35	233	18	266	20
All regions	2,698	27	3,364	33	2,122	21	1,973	19
Soil adsorbed loss potential:								
Delta	1,956	66	1,011	34	7	0	--	--
Southeast	93	11	650	76	109	13	--	--
Southern Plains	1,558	31	3,443	68	40	1	--	--
West	494	38	781	61	14	1	--	--
All regions	4,100	40	5,887	58	170	2	--	--
Soil runoff solution potential:								
Delta	1,963	66	1,004	34	7	0	--	--
Southeast	120	14	714	84	17	2	--	--
Southern Plains	1,560	31	3,441	68	40	1	--	--
West	508	39	767	59	14	1	--	--
All regions	4,151	41	5,928	58	78	1	--	--

-- = Not applicable.

Figure A-3--Procedures used to estimate pesticide loss potential based on chemical properties

1. Algorithm used to estimate pesticide-leaching potential

A pesticide has a *LARGE* leaching potential if:
Log(Half-Life)*(4-Log(Koc)) >= 2.8.

A pesticide has a *SMALL* leaching potential if:
Log(Half-Life)*(4-Log(Koc)) <= 1.8.

A pesticide has an *EXTRA SMALL* leaching potential if:
Log(Half-Life)*(4-Log(Koc)) <= 0.0, or
Solubility < 1 and Half-Life <= 1.

A pesticide has a *MEDIUM* leaching potential in all other cases.

2. Algorithm used to estimate pesticide adsorbed runoff potential

A pesticide has a *LARGE* adsorbed runoff potential if:
Half-Life >= 40 and Koc >= 1,000 or
Half-Life >= 40 and Koc >= 500 and solubility <= 0.5.

A pesticide has a *MEDIUM* adsorbed runoff potential if:
Half-Life <= 1 or
Half-Life <= 2 and Koc <= 500 or
Half-Life <= 4 and Koc <= 900 and solubility >= 0.5 or
Half-Life <= 40 and Koc <= 500 and solubility >= 0.5 or
Half-Life <= 40 and Koc <= 900 and solubility >= 2.

A pesticide has a *SMALL* adsorbed runoff potential in all other cases.

3. Algorithm used to estimate pesticide runoff solution potential

A pesticide has a *LARGE* runoff solution potential if:
Solubility >= 1 and Half-Life > 35 and Koc < 100,000 or
Solubility >= 10 and solubility < 100 and Koc <= 700.

A pesticide has a *SMALL* runoff solution potential if:
Koc >= 100,000 or
Koc >= 1,000 and Half-Life <= 1 or
Solubility < 0.5 and Half-Life < 35.

A pesticide has a *MEDIUM* runoff solution potential in all other cases.

Table A-2--Chemical properties of pesticides covered in the 1989 cotton survey

Soils with large potential for pesticides to dissolve in runoff or attach to eroding soils were most widespread.

Chemical name	Chemical class	Chemical-leaching potential	Adsorption loss potential	Runoff solution loss potential
Arsenic Acid	Desiccant/Defoliant	Extra Small	Large	Small
Dimethipin	Desiccant/Defoliant	Large	Small	Medium
Endothall	Desiccant/Defoliant	Unknown	Unknown	Unknown
Phosphorotrihoate	Desiccant/Defoliant	Small	Medium	Medium
Paraquat	Desiccant/Defoliant	Extra Small	Large	Small
Sodium Cacodylate	Desiccant/Defoliant	Unknown	Unknown	Unknown
Sodium Chlorate	Desiccant/Defoliant	Unknown	Unknown	Unknown
Thidiazuron	Desiccant/Defoliant	Medium	Small	Large
Mancozeb	Fungicide	Small	Large	Medium
PCNB	Fungicide	Small	Large	Small
Etridiazole	Fungicide	Small	Large	Medium
Etridiazole-Disulfoton	Fungicide	Small	Medium	Medium
Etridiazole-Phorate	Fungicide	Small	Large	Medium
Sulphur	Fungicide	Unknown	Unknown	Unknown
Pseudomoras Flouroscens	Fungicide	Unknown	Unknown	Unknown
Metalaxyl	Fungicide	Medium	Medium	Medium
Ethephon	Growth Regulator	Extra Small	Medium	Small
Mepiquat Chloride	Growth Regulator	Small	Large	Small
Basalin	Herbicide	Unknown	Unknown	Unknown
Cyanazine	Herbicide	Medium	Small	Medium
Prometryn	Herbicide	Small	Medium	Large
Fluometuron	Herbicide	Medium	Medium	Medium
Fluometuron+MSMA	Herbicide	Medium	Medium	Medium
DCPA	Herbicide	Small	Large	Medium
Dalapon 85	Herbicide	Large	Small	Medium
Diuron	Herbicide	Large	Small	Small
DSMA	Herbicide	Unknown	Unknown	Unknown
Metolachlor	Herbicide	Medium	Medium	Medium
Enide 90W	Herbicide	Unknown	Unknown	Unknown
EPTC	Herbicide	Medium	Small	Medium
Fluazifop-P-Butyl	Herbicide	Small	Large	Large
Oxyfluorfen	Herbicide	Extra Small	Large	Large
Alachlor	Herbicide	Medium	Small	Medium
Linùron	Herbicide	Medium	Medium	Large
MSMA	Herbicide	Small	Large	Large
Paraquat	Herbicide	Extra Small	Large	Small
Sethoxydim	Herbicide	Small	Small	Medium
Bensulide	Herbicide	Small	Large	Medium
Methazole	Herbicide	Small	Large	Large
Pendimethalin	Herbicide	Small	Large	Medium
Glyphosate	Herbicide	Small	Large	Medium
Sancap 80W	Herbicide	Unknown	Unknown	Unknown
Paraquat+Diuron	Herbicide	Medium	Large	Large
Oryzalin	Herbicide	Small	Large	Large
Trifluralin	Herbicide	Small	Large	Medium
Norflurzon	Herbicide	Medium	Medium	Medium
Acephate	Insecticide	Small	Small	Medium
Aldicarb	Insecticide	Large	Small	Medium
Azinphosmethyl	Insecticide	Small	Large	Large
Bacillus Thuringensis	Insecticide	Unknown	Unknown	Unknown

Continued --

Table A-2--Chemical properties of pesticides covered in the 1989 cotton survey (continued)

Chemical name	Chemical class	Chemical-leaching potential	Adsorption loss potential	Runoff solution loss potential
Bifenthrin	Insecticide	Extra Small	Medium	Small
Carbaryl	Insecticide	Small	Small	Medium
Carbofuran	Insecticide	Large	Small	Small
Chlordimeform	Insecticide	Extra Small	Large	Small
Chlorpyrifos	Insecticide	Small	Large	Large
Cypermethrin	Insecticide	Extra Small	Medium	Small
Cyfluthrin	Insecticide	Small	Large	Medium
Diazinon	Insecticide	Large	Small	Medium
Dimethoate	Insecticide	Medium	Small	Medium
Dicofol	Insecticide	Extra Small	Large	Small
Dicrotophos	Insecticide	Medium	Medium	Small
Diflubenzuron	Insecticide	Small	Large	Medium
Disulfoton	Insecticide	Small	Medium	Medium
Endosulfon	Insecticide	Extra Small	Large	Medium
Esfenvalerate	Insecticide	Small	Large	Large
Ethyl Parathion	Insecticide	Small	Medium	Medium
Ethyl methyl Parathon	Insecticide	Small	Medium	Medium
Fenamiphos	Insecticide	Medium	Medium	Medium
Fenvalerate	Insecticide	Small	Large	Large
Flucythrinate	Insecticide	Extra Small	Large	Medium
Lambdacyhalothrin	Insecticide	Unknown	Unknown	Unknown
Malathion	Insecticide	Small	Small	Small
Metam Sodium	Insecticide	Medium	Small	Medium
Methamidaphos	Insecticide	Small	Small	Medium
Methidathion	Insecticide	Medium	Small	Medium
Methomyl	Insecticide	Large	Small	Medium
Methyl Parathion	Insecticide	Small	Medium	Medium
Moncrotophos	Insecticide	Large	Small	Medium
Naled	Insecticide	Small	Small	Medium
Oxydemetonmethyl	Insecticide	Large	Small	Medium
Oxamyl	Insecticide	Small	Medium	Large
Permethrin	Insecticide	Extra Small	Large	Medium
Phosmet	Insecticide	Small	Small	Medium
Phorate	Insecticide	Small	Large	Medium
Phosphamidon	Insecticide	Large	Small	Medium
Profenfos	Insecticide	Small	Large	Large
Propargite	Insecticide	Small	Medium	Medium
Sulphur	Insecticide	Unknown	Unknown	Unknown
Sulprofos	Insecticide	Small	Small	Medium
Thiodicarb	Insecticide	Small	Small	Medium
Tralomethrin	Insecticide	Extra Small	Medium	Small
Trichlorfon	Insecticide	Large	Small	Medium
One-3-D	Insecticide	Small	Small	Medium
One-3-d-Chloropicrin	Insecticide	Small	Small	Medium
One-3-D-Mic	Insecticide	Medium	Small	Medium
Methyl para endosulfin	Insecticide	Extra Small	Medium	Large
Methyl para permethrin	Insecticide	Extra Small	Large	Medium

Table A-3--Potential for pesticide losses via leaching, adsorption, or runoff based on chemical properties, 1989

Vulnerability to pesticides leaving cropland attached to soil particles was most widespread.

Region	Large		Medium		Small		Extra small		Unknown	
	1,000 acres	*Percent*	*1,000 acres*	*Percent*	*1,000 acres*	*Percent*	*1,000 acres*	*Percent*	*1,000 acres*	*Percent*
Pesticide-leaching potential:										
Delta	653	22	328	11	1,414	48	55	2	523	18
Southeast	103	12	21	2	471	55	23	3	234	27
Southern Plains	58	1	583	12	2,827	56	1,107	22	466	9
West	20	2	32	2	163	13	108	8	967	75
All regions	834	8	964	9	4,875	48	1,293	13	2,190	22
Pesticide adsorption loss potential:										
Delta	53	2	1,561	52	45	2	--	--	1,315	44
Southeast	54	6	214	25	253	30	--	--	330	39
Southern Plains	3,548	70	792	16	139	3	--	--	561	11
West	78	6	158	12	84	7	--	--	970	75
All regions	3,733	37	2,725	27	521	5	--	--	3,176	31
Pesticide runoff solution potential:										
Delta	301	10	1,324	45	34	1	--	--	1,315	44
Southeast	17	2	238	28	266	31	--	--	330	39
Southern Plains	501	10	3,524	70	455	9	--	--	561	11
West	17	1	173	13	130	10	--	--	970	75
All regions	836	8	5,259	52	885	9	--	--	3,176	31

-- = Not applicable.

Figure A-4--Potential pesticide losses screening matrices, 1989

Cropland vulnerability is jointly determined by the chemical properties of the pesticide and of the soil.

Pesticide leaching loss screening matrix:

	Pesticide-leaching potential:			
Soil-leaching potential	Large	Medium	Small	Extra Small
High	Potential 1	Potential 1	Potential 2	Potential 3
Intermediate	Potential 1	Potential 2	Potential 3	Potential 4
Low	Potential 2	Potential 3	Potential 3	Potential 4
Very Low	Potential 3	Potential 3	Potential 4	Potential 4

Pesticide adsorption loss screening matrix:

	Pesticide adsorbed loss potential:			
Soil adsorption loss potential				
High	Potential 1	Potential 1	Potential 2	--
Intermediate	Potential 1	Potential 2	Potential 3	--
Low	Potential 2	Potential 3	Potential 3	--

Pesticide runoff solution loss screening matrix:

	Pesticide solution loss potential:			
Soil solution loss potential				
High	Potential 1	Potential 1	Potential 2	--
Intermediate	Potential 1	Potential 2	Potential 3	--
Low	Potential 2	Potential 3	Potential 3	--

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Monographs

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Cotton Ginning Charges, Harvesting Practices, and Selected Marketing Costs, 1989/90 Season, by Edward H. Glade and Mae Dean Johnson. 4 pp. October 1989. **Order # AGES 9065. $4.00.** Finds that the average charge for saw-ginning and wrapping a 480-pound net-weight bale of U.S. upland cotton was $44.26 during 1989/90, compared with $45.14 per bale the previous season.

Cotton Production Costs Vary Widely by Region, Yield, and Operation Size, by Kenneth H. Mathews, Jr., and others. 11 pp. January 1991. **Order # AIB-617. $4.00.** Describes the cost of producing cotton in 1987 to see how yield, size, irrigation and other inputs, land tenure, and producer age and education affected cotton production costs among and within regions.

Cotton Agricultural Chemical Use and Farming Practices in 1989: An Overview of Survey Results, by Stephen R. Crutchfield. 17 pp. December 1990. **Order # AGES 9076. $4.00.** Summarizes current cotton production practices regarding pesticide and fertilizer use, pest management practices, soil conservation and tillage practices, water use, and characteristics of cotton producers.

Cotton: State-Level Costs of Production, 1986-88, by Kenneth H. Mathews, Jr., and others. 27 pp. September 1990. **Order # AGES 9061. $8.00.**

Fibers: Background for 1990 Farm Legislation, by Harold Stults and others. 89 pp. March 1990. **Order # AIB-591. $11.00.** Congress recently enacted new farm legislation to replace the Food Security Act of 1985. This background paper summarizes in a nontechnical form the experience with various farm programs and the key characteristics of the commodity and the farm industry producing it.

Program Provisions for Rye, Dry Edible Beans, Oil Crops, Tobacco, Sugar, Honey, Wool, Mohair, Gum Naval Stores, and Dairy Products: A Database for 1961-90, by Robert C. Green. 55 pp. June 1991. **Order # AGES 9128. $11.00.** Summarizes the legislative authority for commodity support programs and gives program-provision data in tables for listed commodities.

Periodicals

Cotton and Wool Situation and Outlook Report. Published 4 times per year; includes a yearbook. Subscription rates: 1 year, $12; 2 years, $23; 3 years, $33. Single copies of any issue, $8. Provides statistics on acreage, production and yield; cotton supply and use and supply and disappearance; prices, imports and exports; mill consumption of cotton, wool and fiber (total and per capita); and raw cotton equivalent of imports and exports.

Foreign Agricultural Trade of the United States. Published 6 times per year, plus 2 supplements. Subscription rates: 1 year, $25; 2 years, $49; 3 years, $72. Updates the quantity and value of U.S. farm exports and imports, and includes data on price trends. The fiscal year supplement, by commodity, provides data on quantity and value of trade for the two most recent years, as well as quantity indexes and an historical series. The calendar year supplement contains commodity-by-country and country-by-commodity data for the most recent year only.

Electronic data products

Cotton and Wool Yearbook. U.S. cotton and wool production, supply, use, trade, and price statistics, 1960-91. Includes domestic and world price series and indexes; State cotton acreage, yield, and production data; and conversions of U.S. textile imports and exports to raw fiber equivalents. Bob Skinner, ERS, 202-219-0840. [Lotus 1-2-3 (.WK1), one 5.25" disk], (2/92). **Order # 89004, $25.00.** Note: Data products are shipped on DOS-compatible 5.25", 360KB diskettes. Dates in parentheses reflect the last update of the databases available. Data products are NOT returnable.